California Agricultural Water Electrical Energy Requirements

FINAL REPORT

December 2003

Prepared for

Public Interest Energy Research Program
Energy in Agriculture Program
California Energy Commission
1516 9th St.
Sacramento, CA 95814

by

Charles Burt, Dan Howes, and Gary Wilson
Irrigation Training and Research Center (ITRC)
California Polytechnic State University (Cal Poly)
San Luis Obispo, CA 93407
805-756-2429
www.itrc.org

ACKNOWLEDGMENTS

The Irrigation Training and Research Center (ITRC) gratefully acknowledges the following agencies for providing tremendous assistance with information utilized in this report to estimate agricultural energy use by sector and region throughout California.

- California Department of Water Resources
- United States Bureau of Reclamation
- California Energy Commission
- Kern County Water Agency
- Metropolitan Water District of Southern California
- Arvin-Edison Water Storage District
- Kern County Water Bank
- Semitropic Water Storage District

The Irrigation Training and Research Center would also like to acknowledge the participants in the November 24, 2003 workshop for their time and effort with reviewing the draft report and providing ideas for future research.

Mr.	Ricardo	Amón	California Energy Commission	Mr.	Joe	Lima	Modesto Irrigation District
Ms.	Lucille	Billingsley	U.S. Bureau of Reclamation	Mr.	Dirk	Marks	MWD of Southern California
Mr.	Dale	Brogan	Delano-Earlimart Irrigation District	Mr.	Tom	Martin	Durham Pump Co.
Mr.	Pete	Canessa	Center for Irrigation Technology	Mr.	Jonas	Minton	California Dept. of Water Resources
Mr.	Larry	Dale	Lawrence Berkeley National Lab	Mr.	Steve	Robertson	Robertson-Bryan, Inc.
Mr.	Mike	Day	Provost and Pritchard Engineering Group	Dr.	Larry	Schwankl	UC Extension, UC Davis
Mr.	Hicham	ElTal	Merced Irrigation District	Mr.	Harry	Starkey	Berrenda Mesa Water Storage District
Mr.	Russ	Freeman	Westlands Water District	Mr.	John	Sugar	California Energy Commission
Mr.	Andy	Geyer	Alsco-Geyer Irrigation	Mr.	Van	Tenney	Glenn-Colusa Irrigation District
Mr.	Lance	Goldsmith	Eurodrip	Mr.	Marc	Van Camp	MBK Engineers
Dr.	Blaine	Hanson	UC Extension, UC Davis	Mr.	Scott	Willett	San Diego Co. Water Authority
Mr.	Rick	Iger	Kern County Water Agency	Dr.	Dennis	Wichelns	Dept. of Agricultural Economics, FSU
Dr.	Pramod	Kulkarni	California Energy Commission	Mr.	Tony	Wong	California Energy Commission
Mr.	Steve	Lewis	Arvin-Edison Water Storage District				

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EXECUTIVE SUMMARY

The Irrigation Training and Research Center (ITRC) at Cal Poly State University, San Luis Obispo, conducted an analysis of the energy used to supply water to California's agriculture and examined potential future trends in the agriculture water community to predict future energy requirements.

A. *Water Currently Destined for Agricultural Irrigation*

Currently, energy use for agricultural water varies by location throughout the state. **Table 1** shows the current estimated electrical energy requirement by sector throughout the state. These estimates have been calculated by ITRC for a typical precipitation year. Explanations of how these estimates were made are found in the body of this report.

For this analysis the state was split into 13 zones based on the DWR ETo Zone Map. The numerical values for each zone are consistent with DWR values; however, some of the zones have been modified. **Figure 1** indicates the zones that have been used for this study. In the figure, all coastal zones (1,3,4) are shown collectively under Zone 3 to reduce clutter.

Table 1. Total electrical energy requirement for agricultural water destinations by sector throughout California for an average year

Modified DWR ETo Zone	Irrig. District Surface Water Pumping MWh/Year	Irrig. District Groundwater Pumping MWh/Year	On-Farm Groundwater Pumping MWh/Year	On-Farm Booster Pumping MWh/Year	Conveyance to Irrig. Districts MWh/Year	Total Electric Energy Use by Zone MWh/Year
1	0	0	54,964	20,852		75,816
3	0	0	365,562	145,076		510,638
4	0	0	61,207	18,132		79,339
6	0	0	401,843	148,034		549,877
8	3,896	137	14,573	21,350		39,957
9	0	0	255,199	87,567		342,767
10	0	0	273,277	58,730		332,007
12a	26,171	27,051	283,381	300,329		636,932
12b	8,307	8,586	159,637	101,075		277,606
14	131,125	2,032	108,394	488,733	450,526	1,180,809
15	514,605	199,386	1,659,804	688,121	1,269,062	4,330,978
16	137,662	8,840	846,938	380,371		1,373,811
18	0	0	14,236	415,152		429,388
Total	**821,800**	**246,000**	**4,499,000**	**2,873,500**	**1,719,600**	

Total Ag. Irrig. Water Electrical Energy Usage	**10,159,900**	**MWh/Year**

Confidence Interval +/-	**10%**

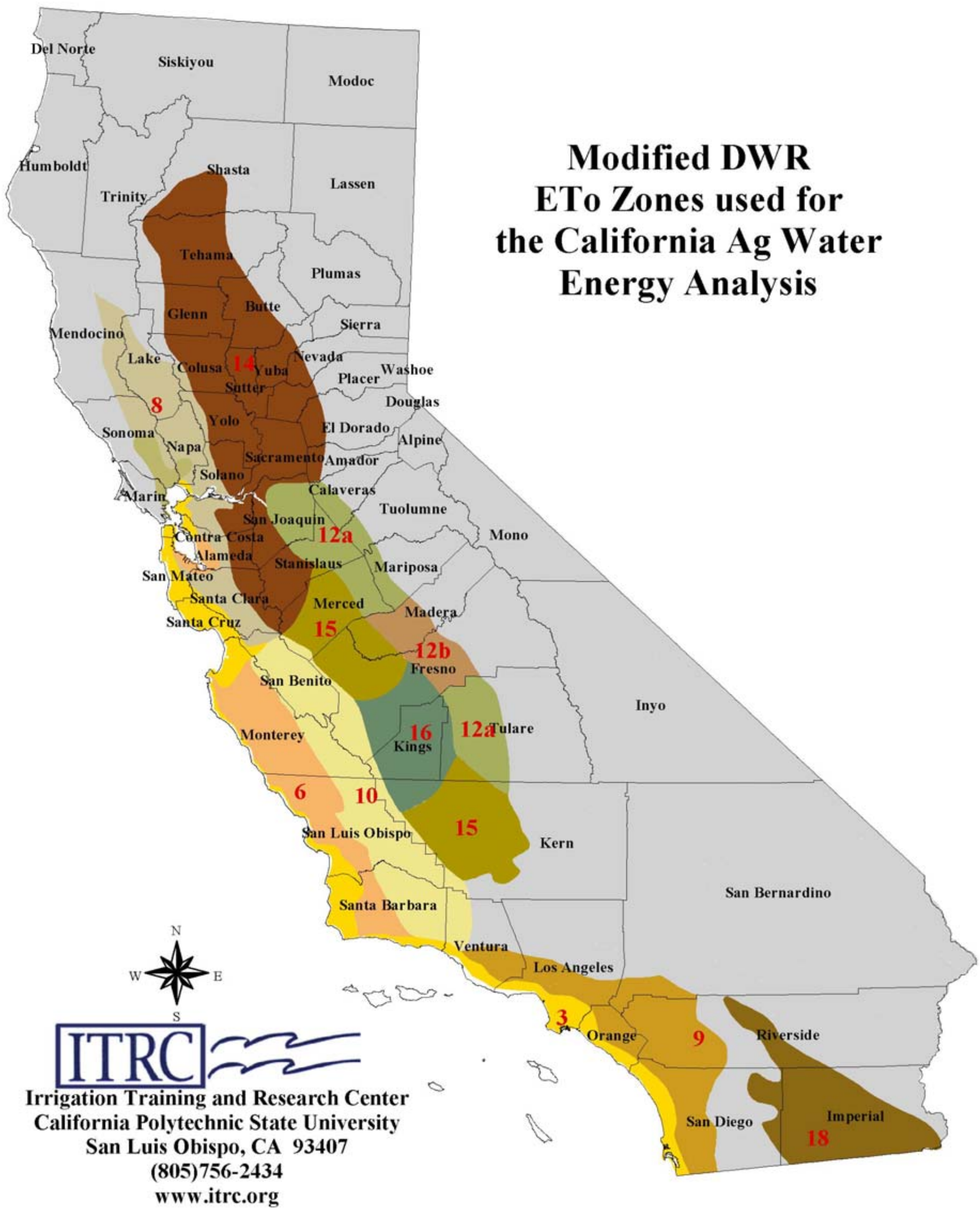


Figure 1. Zones used for the agricultural energy analysis. Zones 1 and 4 are included in Zone 3 on the map.

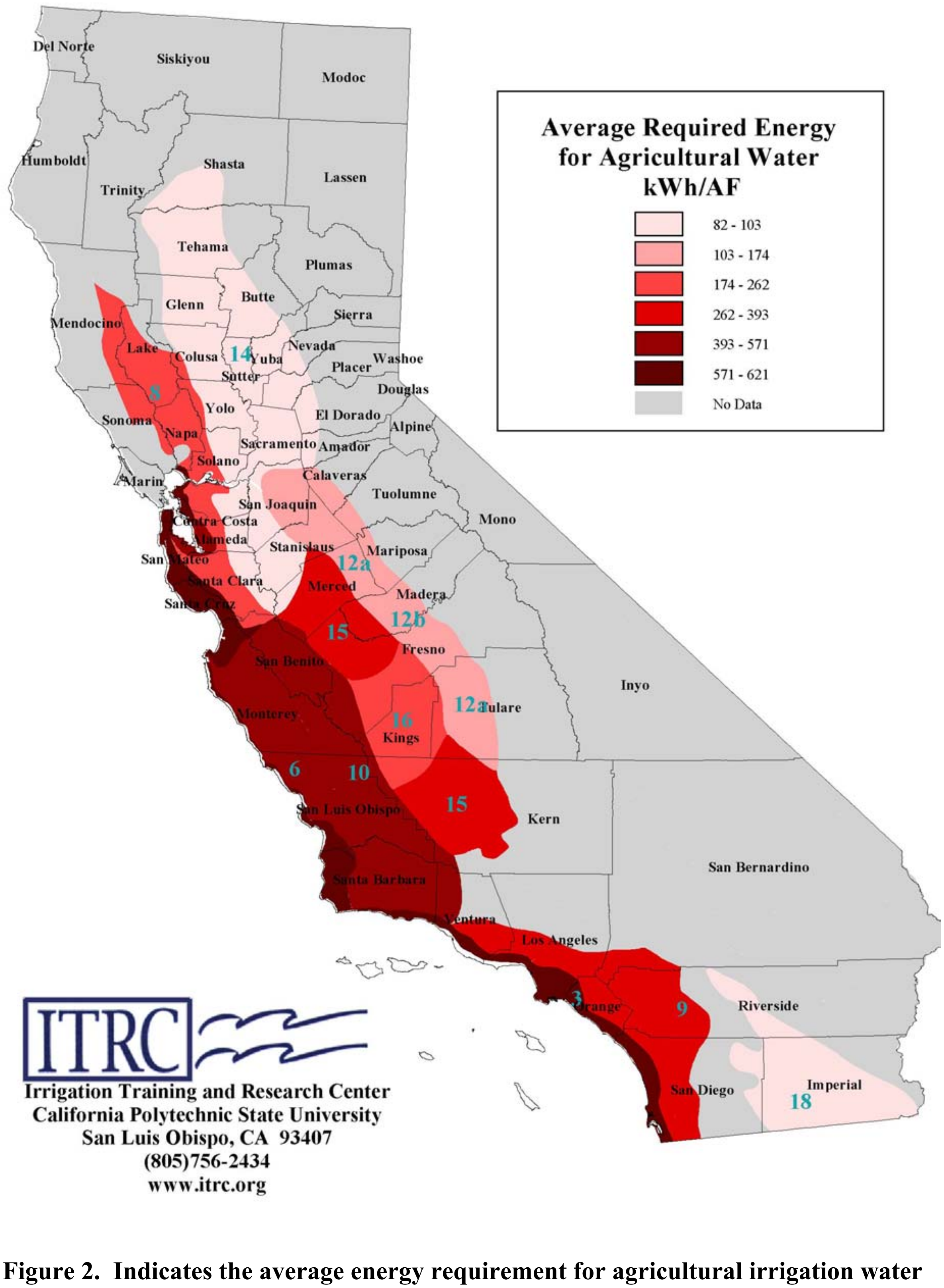


Figure 2. Indicates the average energy requirement for agricultural irrigation water applied in each zone (KWh/AF) during an average year

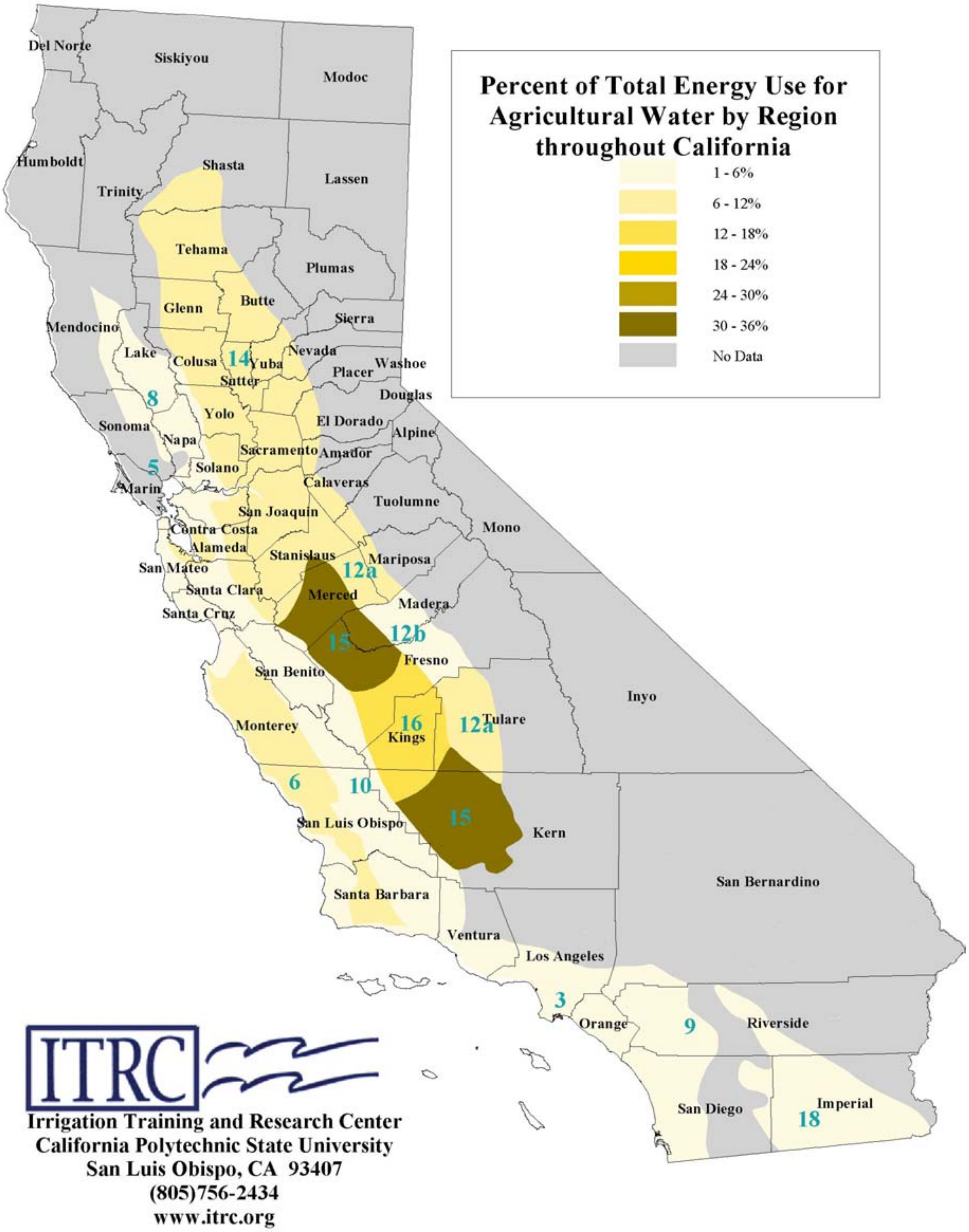


Figure 3. Shows where the majority of energy is used in the state for agricultural pumping. However, Zone 15 is in Kern County and western Fresno and Merced Counties. Most of the zone energy is used in Kern County for pumping.

The statewide total applied agricultural irrigation water is shown in the table below. The values on a regional basis were estimated using a) evapotranspiration of irrigation water values developed by ITRC for crops using different irrigation methods throughout the state, b) estimated distribution uniformities for different irrigation methods, and c) frost protection and water required for leaching salts from the rootzone. Data regarding irrigation type, acreage and irrigation deliveries for an average year in each zone were obtained from information gathered by ITRC.

Table 2. Estimated total applied irrigation water by source for an average year

DWR ETo	Irrig. District Surface Water Delivered	Irrig. District Groundwater Pumping	On-Farm Groundwater Pumping	Total Applied Water by Zone
Zone	AF/Year	AF/Year	AF/Year	AF/Year
1	0	0	123,965	123,965
3	0	0	824,486	824,486
4	0	0	138,046	138,046
6	0	0	959,939	959,939
8	116,140	681	56,387	173,209
9	0	0	880,841	880,841
10	0	0	669,478	669,478
12a	3,025,343	129,393	972,963	4,127,699
12b	960,284	41,071	559,014	1,560,369
14	8,349,919	14,048	425,118	8,789,086
15	4,175,145	505,920	3,880,110	8,561,175
16	2,655,088	43,121	2,533,649	5,231,858
18	4,128,768	0	61,432	4,190,200
Total	**23,410,700**	**734,200**	**12,085,400**	

Total Irrigation Water Applied	**36,230,300**	**AF/Year**

Confidence Interval +/-	**9%**

Table 1 and **Figure 3** indicate that the majority of energy use in California for agricultural pumping occurs in the Sacramento and San Joaquin Valleys, where the majority of agriculture is located. However, **Figure 2** indicates that the energy requirement for irrigation water is highest in coastal regions of California. The reason for this, as shown in **Table 2**, is that the coastal regions do not have a supplemental surface water supply source and farmers must pump groundwater, which requires significant energy.

B. Transfer of Historical Agricultural Water to MWD

Currently, Metropolitan Water District of Southern California (MWD of SC) has water transfer agreements with Imperial Irrigation District, Palo Verde Irrigation District, Coachella Valley Water District, and some groundwater banking districts in Kern County, as well as irrigation districts in Northern California. Some of these transfer agreements are with agricultural users of Colorado River water, shown in **Table 3**.

Table 3. Water Transfer Agreement for the Colorado River Basin to MWD of SC

District	Status	AF/year	MWh/AF	Total MWh
IID	In Place	105,000	2.178	230,000
PVID	Pending	25,000 to 111,000	2.074	52,000 to 230,000
CVWD	In Place	60,000	NA	NA

IID - Imperial Irrigation District
PVID - Palo Verde Irrigation District
CVWD - Coachella Valley Water District

The Imperial Irrigation District (IID) agreement was signed in 1990 and fully implemented by 1998. The Palo Verde Irrigation District (PVID) Agreement has been tentatively approved but must await approval of the QSA (Qualification Settlement Agreement) currently being negotiated. If the QSA were finalized, the PVID transfer could occur within a few months. The Coachella Valley Water District (CVWD) agreement is in reality an exchange, not a transfer. It involves exchanging water that CVWD is entitled to, and has paid for, from the California Aqueduct, with Colorado River water that MWD is entitled to. This is essentially a bucket for bucket exchange. CVWD has no physical means to receive California Aqueduct water without building an expensive pipeline, and MWD is able to provide water to CVWD out of their Colorado River Aqueduct.

The MWD also has transfer agreements and purchases with agricultural water users in the northern part of the state as shown in **Table 4**.

Table 4. One-year (2003) water transfer options exercised by MWD

Water Agency	Amount of Water Transferred (AF)
Glenn-Colusa Irrigation District	50,000
Western Canal Water District	20,000
Richvale Irrigation District	17,200
Meridian Farms Mutual Water Company, Natomas Central Mutual Water Company, Pelger Mutual Water Company, Pleasant Grove-Verona Mutual Water Company, Reclamation District 108, River Garden Farms, Sutter Mutual Water Company	50,000

These one-year water transfers were agreed to by the irrigation districts because of a reduction in State Water Project supplies to MWD resulting from a relatively dry year throughout the state. Farmers within each district voluntarily agreed to fallow land (generally it was originally planted to rice) or plant crops that would use less water. In certain infrequent instances groundwater was substituted for surface water. As reimbursement, MWD paid $100 per acre-foot of estimated crop irrigation water use savings.

The energy consumption that results from such transfers depends on what MWD decides to do with the water. MWD can bank the water in groundwater banking facilities so that it can be utilized at a future date, or it can take the water directly. The following table shows the estimated energy requirements for these options. Banking the water has an additional energy component for moving the water from the California Aqueduct to the banking facilities, and for pumping to get the water out of the groundwater aquifer and back into the California Aqueduct. More detailed discussion of groundwater banking can be found in the body of this report, as well as in **Attachments G** and **H**.

Table 5. Energy requirements for water transfers from Northern to Southern California

Scenarios	Added Energy Component KWh/AF	Total Energy Requirement KWh/AF
Direct transfer from Northern California to MWD	--	3,850
Banking Options		
Arvin-Edison WSD	1,100	4,950
Semitropic WSD	650	4,500
Kern County Water Agency	400	4,250

C. Potential Future Energy Requirements

There are many possible scenarios that could take place in the future that will have an impact on future energy requirements. The following are some of the possible scenarios that are likely to occur.

Scenario 1

This scenario includes a doubling in drip/microspray acreage throughout the state. Many of the converted irrigation systems are assumed to operate solely on groundwater as opposed to district-supplied surface water. The actual percentage differs by region and is shown in the Potential Future Energy Requirement Section of the main report. These farmers that opt to use well water rather than surface water when they switch to drip irrigation do so for two primary reasons: (a) they have the water available "on demand", and (b) the water is generally cleaner, and requires less filtration than does surface water.

Table 6. Total future electric energy requirements with a doubling in drip/micro acreage throughout California by region.

DWR ETo Zone	Irrig. District Surface Water Pumping MWh/Year	Irrig. District Groundwater Pumping MWh/Year	On-Farm Groundwater Pumping MWh/Year	On-Farm Booster Pumping MWh/Year	Conveyance to Irrig. Districts MWh/Year	Total Electric Energy Use by Zone MWh/Year
1	0	0	53,835	23,053		76,889
3	0	0	355,053	172,310		527,362
4	0	0	56,504	24,842		81,346
6	0	0	369,899	171,295		541,194
8	3,896	137	14,282	44,777		63,091
9	0	0	237,094	119,989		357,082
10	0	0	270,699	72,199		342,899
12a	26,171	27,051	502,237	559,400		1,114,859
12b	8,307	8,586	248,337	190,200		455,431
14	131,125	2,032	306,254	762,535	450,526	1,652,471
15	514,605	199,386	1,887,797	965,421	1,269,062	4,836,272
16	137,662	8,840	894,352	493,252		1,534,105
18	0	0	13,505	480,644		494,149
Total	**821,800**	**246,000**	**5,209,800**	**4,079,900**	**1,719,600**	

Total Ag. Irrig. Water Electrical Energy Usage	**12,077,100**	**MWh/Year**
Increase in Electrical Energy Usage:	**1,917,200**	**MWh/Year**

Scenario 2a

Three hundred thousand additional acre-feet of surface water are transferred from the Delta for municipal use in Southern California. This assumes fallowing or crop shifting of irrigated acreage for the transfer. Water that is transferred will **not** be replaced by on-farm groundwater pumping.

	District Surface Water Pumping MWH/Year	District Groundwater Pumping MWH/Year	On-Farm Groundwater Pumping MWH/Year	On-Farm Booster Pumping MWH/Year	Conveyance to Districts MWH/Year	Energy for Water Transfers MWH/Year	Total Energy Use for CA Ag Water MWH/Year
Current	**821,800**	**246,000**	**4,499,000**	**2,873,500**	**1,719,600**	**Variable**	**10,159,900**
New	**817,100**	**246,000**	**4,499,000**	**2,873,500**	**1,719,600**	**+1,139,700**	**11,294,900**
						Increase:	**1,135,000**

Scenario 2b

Three hundred thousand additional acre-feet of surface water are transferred from the Delta for municipal use in Southern California. This assumes no fallowing of irrigated acreage for the transfer. Water that is transferred will be replaced by on-farm groundwater pumping.

	District Surface Water Pumping	District Groundwater Pumping	On-Farm Groundwater Pumping	On-Farm Booster Pumping	Conveyance to Districts	Energy for Water Transfers	Total Energy Use for CA Ag Water
	MWh/Year	MWh/Year	MWh/Year	MWh/Year	MWh/Year	MWh/Year	MWh/Year
Current	**821,800**	**246,000**	**4,499,000**	**2,873,500**	**1,719,600**	**Variable**	**10,159,900**
New	**817,100**	**246,000**	**4,575,500**	**2,873,500**	**1,719,600**	**+1,139,700**	**11,371,400**
						Increase:	**1,211,500**

Scenario 3a

An additional 100,000 AF of surface water is transferred from Northern California for agricultural use in Westlands Water District. This assumes fallowing or crop shifting of irrigated acreage for the transfer. Water that is transferred will **not** be replaced by on-farm groundwater pumping.

	District Surface Water Pumping	District Groundwater Pumping	On-Farm Groundwater Pumping	On-Farm Booster Pumping	Conveyance to Districts	Energy for Water Transfers	Total Energy Use for CA Ag Water
	MWH/Year	MWH/Year	MWH/Year	MWH/Year	MWH/Year	MWH/Year	MWH/Year
Current	**821,800**	**246,000**	**4,499,000**	**2,873,500**	**1,719,600**	**Variable**	**10,159,900**
New	**820,200**	**246,000**	**4,499,000**	**2,873,500**	**1,719,600**	**+34,700**	**10,193,000**
						Increase:	**33,100**

Note that the +34,700 MWh/Year for water transfers could have been placed into the "Conveyance to Districts" column, rather than in the "Energy for Water Transfers" column.

Scenario 3b

An additional 100,000 AF of surface water is transferred from Northern California for agricultural use in Westlands Water District. This assumes no fallowing of irrigated acreage for the transfer. Water that is transferred will be replaced by on-farm groundwater pumping.

	District Surface Water Pumping	District Groundwater Pumping	On-Farm Groundwater Pumping	On-Farm Booster Pumping	Conveyance to Districts	Energy for Water Transfers	Total Energy Use for CA Ag Water
	MWh/Year	MWh/Year	MWh/Year	MWh/Year	MWh/Year	MWh/Year	MWh/Year
Current	**821,800**	**246,000**	**4,499,000**	**2,873,500**	**1,719,600**	**Variable**	**10,159,900**
New	**820,200**	**246,000**	**4,524,500**	**2,873,500**	**1,719,600**	**+34,700**	**10,218,500**
						Increase:	**58,600**

Note that the +34,700 MWh/Year for water transfers could have been placed into the "Conveyance to Districts" column, rather than in the "Energy for Water Transfers" column.

Scenario 4

The water transfer agreement between San Diego County Water Authority and Imperial Irrigation District takes place.

Total Loss of Generation = 178 KWh/AF

Colorado Aqueduct Pumping Requirement
(Wilkinson Report and personal communication
with MWD of SC) = 2,000 KWh/AF

Total Energy Component = 2,000+178 (KWh/AF) = 2,178 KWh/AF (2.18 MWH/AF)

Assuming an additional 100,000 AF transfer were to occur, the total energy component would be:

+**218,000 MWh/Year**

Scenario 5

The table below shows the maximum potential energy requirements for major groundwater banking districts in California that will likely send storage to Metropolitan Water District of Southern California (MWD). These districts are located in Kern County.

Table 7. Energy requirement when maximum withdrawal occurs

District		Maximum AF Returned to MWD	MWH/AF	MWh/Year
Arvin-Edison WSD	Maximum	75,000	1.1	82,500
Semitropic WSD	Return	90,000	0.65	58,500
	In Lieu	133,000	0.485	64,505
Kern County WA	Maximum	240,000	0.4	96,000
TOTAL (max)		538,000		301,505

The values in the table above indicate the annual maximum volume of water that theoretically could be returned to MWD. However, it is highly improbable that the volume of water returned would be this high. Nevertheless, this scenario provides a potential maximum energy requirement for current water banking programs in the southern portion of the San Joaquin Valley. Case studies for each of these water banks can be found in **Attachment F** and a complete discussion of water banking can be found in the body of this report.

Scenario 6. Desalination of Drainage Water

The cost and energy requirement for desalination has decreased dramatically over the past decade. The advent of low pressure reverse osmosis technology has been one of the major factors contributing to this decrease in operating cost. The decreasing cost of desalination opens up the potential for use by the agricultural sector. Drainage water along the west side of the Central Valley is very high in salts, specifically selenium. Restrictions on disposal of this drainage water have caused significant problems throughout this region.

Between 200,000 and 300,000 acre-feet (AF) of drain water could be discharged annually from the Westside of the Central Valley. A current estimated energy requirement for desalination of drainage water is approximately 2.5 MWH/AF for water with a salinity level between 5,000 and 10,000 mg/L. If 300,000 AF of drainage water were treated using desalination, the estimated annual energy requirement would be 750,000 MWh, plus the transportation costs.

There is potential that utilizing solar ponds for brine disposal could produce some of this energy. Brine disposal is one, if not the most important, factor for inland desalination plants. Further research on solar ponds and feasibility studies on brine disposal in general are needed to examine the potential for desalination of drainage water in the San Joaquin Valley.

Scenario 7. Fuel Switching

In recent years there has been a significant increase in the conversion from electric motors to diesel engines for pumping throughout California because of the significant increase in the cost of electricity. However, because of air quality concerns and new regulations there may be a shift back to electric motors. This may require incentive programs to help reduce the cost of electricity.

This scenario assumes a conversion of 50% of the current engines in each zone to electric motors. The table below shows the change.

	Original Estimate of On-Farm Pumping Fuel Source		Scenario 7 Estimate of On-Farm Pumping Fuel Source	
	Electric	Non-Electric	Electric	Non-Electric
Zone	%	%	%	%
1	90	10	95	5
3	90	10	95	5
4	90	10	95	5
6	95	5	97.5	2.5
8	90	10	95	5
9	80	20	90	10
10	80	20	90	10
12	80	20	90	10
13	80	20	90	10
14	65	35	82.5	17.5
15	70	30	85	15
16	70	30	85	15
18	90	10	95	5

	District Surface Water Pumping	District Groundwater Pumping	On-Farm Groundwater Pumping	On-Farm Booster Pumping	Conveyance to Districts	Energy for Water Transfers	Total Energy Use for CA Ag Water
	MWH/Year	MWH/Year	MWH/Year	MWH/Year	MWH/Year	MWH/Year	MWH/Year
Current	**821,800**	**246,000**	**4,499,000**	**2,873,500**	**1,719,600**	**Variable**	**10,159,900**
New	**821,800**	**246,000**	**5,026,700**	**3,208,800**	**1,719,600**	**+0**	**11,022,900**
						Increase	**863,000**

Ranchettes

The analysis of energy used for agricultural pumping did not include information regarding municipal and industrial water pumping. However, a popular form of urbanization in the Central Valley is to convert agriculture land to "ranchettes." Ranchettes are large lots, typically 0.5 to 8 acres, with a single-family dwelling. This provides the potential for hobby farming as well as raising horses or other animals. If the ranchettes are irrigated there is a potential impact on energy usage. Since most irrigation districts in California were not designed to supply water to small parcels, these ranchette owners could be forced to pump groundwater for irrigation.

In order to determine if ranchettes are being irrigated, ITRC conducted a GIS analysis utilizing LandSat images and California DWR Land Use shapefiles. Using the satellite images taken in mid-summer, the vegetative index was calculated. Utilizing the DWR land use data, the irrigated versus non-irrigated areas for small parcels in Tulare, Fresno, Kern, and Sacramento Counties were determined (a detailed explanation of the analysis can be found in **Attachment E**). The results of this evaluation are shown in the table below.

Table 8. Percent of ranchette acreage that is irrigated

	Total Sample Size	Total Irrigated	Percent Irrigated Vegetation
Region	**Acres**	**Acres**	**%**
Fresno	16,533	1,795	**11%**
Kern	8,340	738	**9%**
Sacramento	15,869	813	**5%**
Tulare	7,878	1,237	**16%**

The results indicate that only a small percentage of the ranchette areas are actually irrigated. From an energy use standpoint, this would lead to a lower overall energy use statewide if this land was converted from irrigated agriculture. However, the energy required per acre of irrigated vegetation could be much higher if the ranchette owner pumps the water or if it is supplied by the local municipal water agency.

D. Reservoir Sensitivity to Global Warming

The sensitivity of reservoir storage to drought and wet conditions will affect the availability of surface water throughout the growing season. A spreadsheet was developed to make general predictions of the reservoir storage levels and outflows when inflows into the reservoir are changed. Data was collected on the reservoirs on the Eastside of the San Joaquin Valley for varying time periods, depending on availability of information, and used to compare the actual inflow, outflow, and storage to an adjusted inflow, outflow and storage.

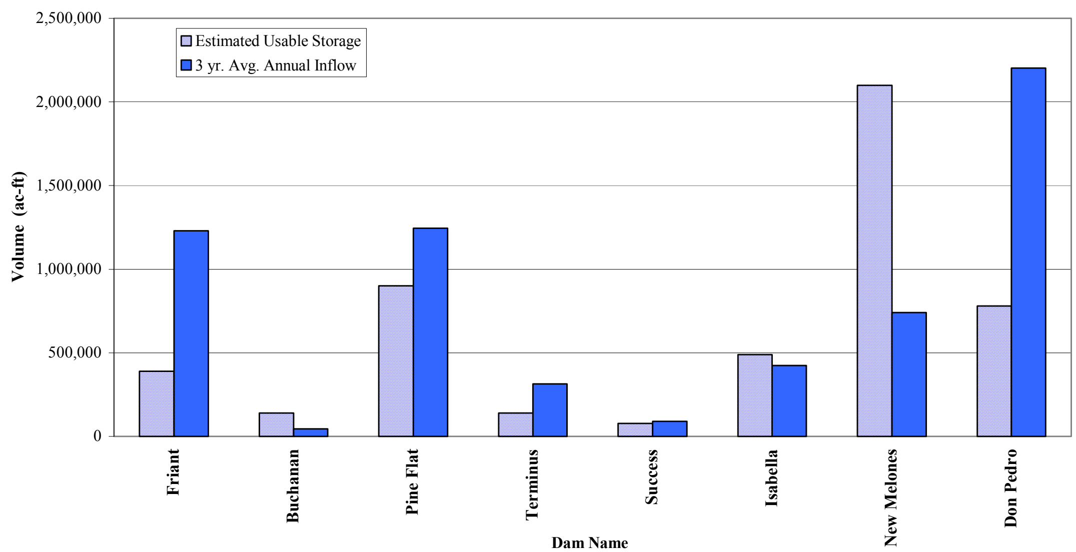
Results

- More precipitation in the form of rain and less snow pack results in earlier runoff.
- Outflows of reservoirs with proportionately smaller capacities and large inflows are most affected by the changed inflow pattern. Large reservoirs are less affected.
- Reservoirs that operate at levels not pushing the maximum and minimum volumes do not show a need to change outflow.
- Outflows that are reduced as a result of the changed inflows do so at the end of the summer when reservoir levels are near their minimum storage capacity. This means surface water deliveries could be cut off earlier or reduced throughout the summer. This effect on outflows would be felt most during dry years. The timing of such reductions depends on the reservoir.
- Outflow changes and resulting power usage due to increased groundwater pumping is included in the table below.

Table 9. Increased power use as a result of earlier runoff. The figure below shows the maximum usable storage and average annual inflow into each reservoir.

	Dam Name															
	Friant		Buchanan		Pine Flat		Terminus		Success		Isabella		New Melones		Don Pedro	
Year	Reduced Summer Outflow (AF)	Resulting MWh increase	Reduced Summer Outflow (AF)	Resulting MWh increase	Reduced Summer Outflow (AF)	Resulting MWh increase	Reduced Summer Outflow (AF)	Resulting MWh increase	Reduced Summer Outflow (AF)	Resulting MWh increase	Reduced Summer Outflow (AF)	Resulting MWh increase	Reduced Summer Outflow (AF)	Resulting MWh increase	Reduced Summer Outflow (AF)	Resulting MWh increase
1996															256,110	93,224
1997															185,312	67,454
1998																
1999																
2000	235,889	84,212	0	0	0	0	32,950	13,510	0	0	0	0	0	0		
2001	166,536	59,453	0	0	0	0	16,291	6,679	1,262	459	0	0	0	0		
2002	150,689	53,796	0	0	86,365	36,273	22,262	9,127	0	0	25,438	15,543	0	0		
Average	**184,371**	**65,821**	**0**	**0**	**28,788**	**12,091**	**23,834**	**9,772**	**421**	**153**	**8,479**	**5,181**	**0**	**0**	**220,711**	**80,339**

Sum of Reservoir Averages	**466,605**	**173,357**



E. Impact of Water Policies

Water-related policies by state and national governments can have a huge impact on energy consumption, and on peak load demand. In general, as government policy has shifted away from more storage and towards water conservation, pumps have provided much of the flexibility to enable that shift. This is not to say that such policies are incorrect; but it does say that there are energy implications for California. For example:

- Drip/micro and sprinkler irrigation are promoted in water conservation plans to improve on-farm irrigation efficiency. The shift from surface irrigation to drip/micro and sprinkler irrigation in many areas of the state has increased on-farm pumping. On the east side of the San Joaquin Valley, most of the irrigation district water does not utilize pumps for transportation. When farmers shift to drip/micro or sprinkler irrigation, at a minimum they install a booster pump. Typically, they also use groundwater rather than surface water when they switch irrigation methods.
- Water quality regulations have reduced the amount of irrigation surface tailwater and canal spillage that can enter rivers and sloughs. Capturing and reusing that water almost always requires pumping plants.
- Policies promote off-stream storage of water (such as groundwater banking or reservoirs such as the San Luis Reservoir) rather than in-stream storage (traditional dams). Almost all off-stream storage projects require pumps to lift water at one stage of the process.
- Water transfers typically require more pumping than do regular deliveries. Water transfers are needed during years of low hydro-electric generation.
- Urbanization causes agriculture in some areas to shift to non-irrigation district lands – where the only water available is groundwater.
- At some times in the southern San Joaquin Valley, low elevation irrigation districts receive water from high elevation sources, but high elevation districts receive water from low elevation sources. Regulations regarding the usage of Federal CVP and California Aqueduct SWP water prevent shifting destinations with a simple paper trade of water – which could result in considerable energy savings.

There does not appear to be any rational, systematic, and analytical process available to policymakers that examines the electric energy impacts of proposed environmental or water policies. Policymakers are therefore unaware of the energy implications of their proposals.

F. Future Research

Future research recommendations were provided by participants of the Nov. 24, 2003 meeting. Those recommendations, plus information from other sources, were incorporated into a March 2004 document entitled "Technology Roadmap – Water Use Efficiency in California Agriculture", by Charles Burt and Ricardo Amon. That report can be found through http://www.itrc.org/reports/cec.html. Four research tracks are recommended, as seen below.

Research Tracks	On-farm Improvements	District or Project Improvements
I. Hardware improvements		
1. Pumping plant-related	a. Improved pump and motor efficiency and durability b. Improved filter construction and operation c. Investigate inlet conditions d. Investigate column dimensions	a. Improved pump and motor efficiency and durability b. Improved filter construction and operation c. Investigate inlet conditions d. Investigate column dimensions e. Optimize operation of supply and drainage wells
2. On-farm irrigation system-related	a. Improved hand-move sprinkler design b. Improved cleaning of drip systems c. Simplified irrigation scheduling d. Research into soft-start/soft-stop hardware	a. Research into soft-start/soft-stop hardware
3. Power-rate-related	a. Power use audits	a. Power use audits, including auditing of delivery strategies
II. Reductions in water demand	a. Investigate use of Regulated Deficit Irrigation (RDI) b. Research into anti-transpirants	a. Investigate novel approaches to reducing system losses b. Drainage water desalinization.
III. Enhanced utilization of surface water 1. Improved delivery flexibility		a. Identify solutions for capacity constraints b. Develop GIS-based scheduling and routing schemes c. Expand real-time turnout data d. Study of Friant-Kern facilities e. Refinement of canal control integration procedures
IV. Assess policy impacts	a. Analysis of implications of legislative and regulatory decisions on agricultural power consumption b. Develop guidelines for incorporation of power consumption in future legislative and regulatory decision making	a. Analysis of implications of legislative and regulatory decisions on agricultural power consumption b. Develop guidelines for incorporation of power consumption in future legislative and regulatory decision making

INTRODUCTION

The Irrigation Training and Research Center (ITRC) at Cal Poly State University San Luis Obispo was contracted by the California Energy Commission to assess the science and policy of agricultural water resource management to determine the impact future water issues will have on the statewide electricity system.

Agricultural water resource management in this case refers to three levels of water consumption/transportation:

- On-farm issues and solutions
- Irrigation district issues and solutions
- Water marketing between agricultural and urban sectors

The objectives of this study are:

1. Define the current science and policies of agricultural water management, as related to California electricity usage.
2. Envision future trends in science and policy that will impact California's future electricity usage.
3. Define areas of potential research, training, and policy modification that can better define future trends or impact the agricultural water/electricity relationship in California.

The initial step was to analyze the current agricultural water energy requirements throughout the state. Three energy use sectors were examined:

- Water District Pumping (Surface and Groundwater)
- On-Farm Pumping (Groundwater and Booster)
- Conveyance to Water District Pumping (Surface Water)

Once the current energy requirements were examined in each sector, different scenarios were examined to help predict future energy requirements. Specifically, energy requirements with regards to water transfers and water banking were examined. Drainage water desalination and irrigation method changes were examined as well.

ANALYSIS OF CURRENT ENERGY REQUIREMENTS

In order to understand where the energy is being used in the state, by location as well as by sector, it was necessary to complete a detailed analysis of irrigation requirements, surface water deliveries, and groundwater use. Studies conducted by the Irrigation Training and Research Center were used in this analysis, including the *Benchmarking of Status and Needs of California Water Districts for 1995*, *2000*, and *2002*, the *Evaporation from Irrigated Agriculture Land in California*, as well as other technical reports conducted throughout the state. District surveys and water management plans for eighty-seven districts throughout California were used to help estimate district and on-farm pumping requirements. These sample districts had a combined irrigated acreage of approximately 4,350,000 out of a total estimated 9,126,200 irrigated acres in California.

California Department of Water Resources ETo zones were used to organize and separate data from throughout the state based on region because ITRC already had data available on the evapotranspiration of irrigation water and crop-irrigation type acreage by these ETo zones. The ETo zones used by ITRC have been slightly modified from the original DWR zones: the numbers are generally the same, but ITRC uses 12 zones (1, 3, 4, 6, 8, 9, 10, 12a, 12b, 14, 15, 16, and 18) instead of the full 18. Zone 12 has been split into two zones and part of the original Zone 12 (a region north of Sacramento) has been included in Zone 14, along with data from Zone 13.

District Surface Water Pumping

The *Benchmarking of Status and Needs Reports* were used to obtain average annual water deliveries, district irrigated acreage, number of groundwater wells, average power cost, and average cost per kilowatt-hour. Irrigation district water management plans were also used to obtain average district deliveries, groundwater-pumping volumes, and irrigated acreage. Details on the methodology and data used for this analysis can be found in **Attachment A**.

The estimated annual energy used for district surface water pumping was determined using different methods depending on what type of information was available. Generally, energy use by district groundwater pumping was determined first (see the next section). Then, the total energy used by each district (groundwater and surface water pumping) was estimated by dividing the average annual power cost by the average cost per kilowatt-hour. Subtracting the energy needed for groundwater pumping from the total energy used by the district gives the energy used for surface water pumping. If a district did not pump groundwater, the total energy usage was assumed to be equal to the energy used for surface water pumping.

The annual energy used by each of the 87 districts for surface water pumping was divided by the annual surface water deliveries to obtain KWh/AF. Utilizing GIS, each district was assigned to a DWR ETo zone based on the district's location in the state. The KWh/AF were weighted based on district size and averaged for each ETo zone. Surface deliveries

(AF/acre) were also weighted by district size and averaged for each ETo zone. The annual energy used for district surface water pumping was then calculated for each zone.

Table 10. Regional and statewide annual electric energy for district surface water pumping.

Modified DWR ETo Zone	Irrig. District Surface Water Pumping MWh/Year
1	0
3	0
4	0
6	0
8	3,896
9	0
10	0
12a	26,171
12b	8,307
14	131,125
15	514,605
16	137,662
18	0
Total	**821,800**

It was assumed that in zones that did have significant surface water deliveries (Central Valley and Southern California desert regions), all agriculture had some surface water rights. Therefore, the amount of water delivered by districts (AF/Acre) in each zone was assumed to be constant for all irrigated agricultural acreage in that zone. This could lead to an underestimation of on-farm groundwater pumping and an overestimation of district deliveries in these zones since some areas may not be contained in a district boundary. However, the error is likely minimal since the most significant regions that do not receive surface water (Coastal Regions) are shown in this report to have zero surface water deliveries.

North Kern Water Storage District
Peak Load Reduction Case Study

Site

The North Kern Water Storage District is located on the Eastside of the San Joaquin Valley in Kern County and encompasses nearly 60,000 acres. The district uses water from the Kern River and groundwater supplies to supply its users.

Problem

The energy emergency caused projected energy rates to increase across the board. The district's large reliance on groundwater consumed over 9 Megawatts of electrical load on the power grid during peak hours.

Solution
North Kern Water Storage District utilized the CEC Agricultural Peak Load Reduction Program administered by the Irrigation Training and Research Center to receive grant funding, of up to 65% of the total project cost, for three projects that have combined to curtail almost the entire 9 MW of peak load.

These projects included:
- Construction and use of regulating reservoirs to supply water to users during the peak period, allowing groundwater pumps to be turned off.
- Installation of telemetry equipment to remotely monitor water levels in reservoirs and canals to help the district operate their distribution system with their current staff.
- Well lining, necessary for most district groundwater wells, to prevent casing failure because of daily startups and shutdowns.
- Installation of timers on over 60 groundwater wells to automatically turn off wells before 12 pm and turn them back on after 6 pm, Monday-Friday, May-October.

These projects also included a partnership with the largest grower in the district, Paramount Farming. Paramount agreed to use only surface water during non-peak times, where possible, to reduce the demand placed on the district. This not only benefited the district, but also enabled Paramount to utilize non-peak energy rates and reduce its own peak load by 340 kW (in the district boundaries).

Results
Currently, on average, over 9 MW of peak load are being curtailed in NKWSD every weekday during the months of June through September. Dana Munn, the district manager/engineer estimates that the CEC APLRP grants are helping to save district water users $20-30 per acre-foot of water delivered by the district.

District Groundwater Pumping

Many of the same sources used to determine district surface water pumping were also used to help determine the energy from district groundwater pumping. However, the procedure was different. First, the average KWh/AF was calculated for each district. Static water level, drawdown, discharge pressure, column loss, and pump efficiency were needed to calculate the KWh/AF value. The average groundwater level for approximately 60 districts was obtained from the benchmarking surveys. The remaining static groundwater levels were estimated using California DWR regional groundwater contour maps. More information on the process and data used for this analysis can be found in **Attachment A**.

Pump companies throughout the state were called and phone interviews were conducted to find information on regional drawdown and column loss components. Drawdown values were averaged for each region. Column loss components, typical flow rates, and column sizes were also averaged for each region and incorporated into the other information for the 87 districts.

Average district pump efficiencies were obtained from the CEC Agricultural Peak Load Reduction Program Water Agency Pump Testing Database. Average pump efficiency for each participating water agency was incorporated into a GIS district database. Because the districts that participated in the pump testing rebate program and the districts analyzed for this report did not necessarily overlap, GIS was used to obtain average pump efficiency for district pumps by ETo zone. The average pump efficiency by zone was then applied to the districts in the respective zones. More information on water agency pump efficiencies can be found in **Attachment C**.

The static water level, drawdown, column loss, and discharge pressure were used to estimate the total dynamic head (TDH). Knowing the TDH and average pump efficiency, the KWh/AF could be calculated for each of the 87 districts. The average annual groundwater pumped by the district was used to estimate the total energy required to pump this groundwater. The volume of groundwater pumped for a typical year by an irrigation district was obtained from water management plans and district phone interviews.

The KWh/AF required for district groundwater pumping was weighted based on district size and averaged for each ETo zone. The volume of groundwater pumped per acre (AF/acre) by each district was also weighted by district size and averaged for each ETo zone. Knowing the total irrigated acreage in each zone, the total energy used for groundwater pumping by districts was then calculated.

Table 11. Regional and statewide electric energy for irrigation district groundwater pumping.

Modified DWR ETo Zone	Irrig. District Groundwater Pumping MWh/Year
1	0
3	0
4	0
6	0
8	137
9	0
10	0
12a	27,051
12b	8,586
14	2,032
15	199,386
16	8,840
18	0
Total	**246,000**

On-Farm Groundwater Pumping

The need for on-farm groundwater pumping was estimated based on evapotranspiration of irrigation water (ETirr), estimated irrigation efficiency, irrigation water needed to meet the leaching requirement (LRw), frost protection water, and district water availability. A long-term study conducted by ITRC analyzed the evapotranspiration requirements for crops throughout California (*CALFED Evaporation from Irrigated Agriculture in California*, ITRC Report No. 02-001). Using a crop water use model based on *FAO Irrigation and Drainage Paper No. 56*, crops in 13 ETo zones were modeled for a wet, dry, and typical year. The model accounted for four soil categories and three irrigation methods. One of the model outputs was ETirr (a detailed discussion of the model and input parameters as well as results can be found in ITRC Report No. 02-001 on the ITRC website, www.itrc.org). The ETirr water for each crop within each ETo zone was used for this analysis. The ETirr used was for a typical precipitation year. Estimated leaching requirement and frost protection water components were also incorporated where necessary. The crop water requirement (ETirr+LRw+frost protection) for each crop in each ETo zone was weighted based on acreage and averaged for each zone.

Table 12. Normal year average crop evapotranspiration of irrigation water (ETirr) demands plus leaching and frost protection requirements (LRw and FP) for crops in each zone. Values are weighted based on crop type acreage and irrigation type acreage in each zone.

Zone	Weighted average of crop evapotranspiration of irrigation water demands, including leaching and frost protection by zone (AF/Acre)
1	1.80
3	1.83
4	2.24
6	2.10
8	2.10
9	2.83
10	2.55
12a	2.67
12b	2.67
14	2.62
15	2.86
16	2.76
18	4.51

An irrigation distribution uniformity value for each irrigation method was estimated based on ITRC experience. This experience includes operating mobile labs throughout the western

United States. The estimated DU for each irrigation type throughout California is shown in the table below.

Table 13. Distribution uniformity estimate for three categories of irrigation methods throughout California

Surface	Sprinkler	Drip/Micro
0.70	**0.75**	**0.80**

We know that there is a difference between the gross irrigation water *requirement* and the gross irrigation water *applied*. An examination of Cal Poly ITRC drip/micro evaluation results on several hundred fields indicates that most orchards and vineyards are under-irrigated during the middle of the summer. That is, farmers are not adjusting their irrigation scheduling according to their actual DUs and the ET requirements. This results in under-irrigation on parts of the fields. Yet we also think that there can be over-irrigation (beyond what is needed for ET and DU considerations) at other times of the year

Extrapolating this limited knowledge to other drip/micro fields, and to surface and sprinkler irrigated fields, is difficult without good data. It is an important item, because PIER, DWR, and USBR are often approached to fund projects that anticipate water savings from improved irrigation scheduling. Because we recognize that there is both under-irrigation and over-irrigation occurring in the state, we have not attempted to apply any “scheduling adjustment” to the computation of pumped water.

An additional factor was included in the estimation of the volume of groundwater pumping. This factor accounts for the unavailability of surface water when farmers need it at specific times of the year. For example, in the Fresno area (Zone 12b) surface water is typically only available until mid-July. After the surface water ceases, farmers must pump groundwater to meet evapotranspiration demands. The calculations used in this study assume that the volume of water delivered by irrigation districts is limited only by volume, not by whether or not the district has surface water to deliver. The additional factor takes this timing aspect into account. This factor will be called the “Timing Factor” (TF).

An obvious question regarding the Timing Factor is, if a specific volume of water was delivered by the district regardless of timing, where did the water go if it did not go to meet the crop irrigation water demands? An important component of irrigation that has not been taken into account is excess duration. The distribution uniformity accounts for differences in depth applied throughout a field. The ETirr value accounts for evaporation from the soil and plant surfaces as well as inaccurate irrigation scheduling frequency, which causes increased crop stress. However, it is nearly impossible to meet the soil moisture depletion exactly. It is highly probable that during early season irrigation when the crop water demands are low, farmers over-irrigate, either to ensure maximum available water in the rootzone or to purposely utilize surface water when it is available to recharge the groundwater so it can be used later in the irrigation season. The Timing Factor accounts for the excess irrigation scheduling duration. The Timing Factor values are shown by region in the table below.

Table 14. Timing Factor used to account for groundwater pumping due to surface water not being available at certain times of the year

Mod. ETo Zone	Timing Factor
1,3,4,6,8,9,10,12a,15,16,18	0.9
12b	0.65
14	0.85

The volume of groundwater pumping per acre differs by irrigation method because of the distribution uniformity associated with that irrigation type. ITRC conducted a study analyzing the acreage of irrigation types in each ETo zone for the *Evaporation from Irrigated Agriculture in California* report (Burt et al., 2002). The four categories of irrigation methods used are Surface, Sprinkler, Drip/Micro, and Sprinkler/Surface combination. Since the DU for each irrigation method is different, the amount of water applied for each irrigation method will also be different. ITRC assumed that districts delivered the same volume of water per acre regardless of irrigation type. Therefore, the estimated volume per acre of water delivered by districts, subtracted from the total volume of water per acre required by farmers results in the amount of groundwater pumped on-farm, which varies depending on irrigation method.

The volume of on-farm groundwater (GW) pumping was calculated using the following equation:

On-Farm GW Pumping = ([(ETirr+LRw+FP)/DU] – (District Deliveries*TF))

Where,

ETirr = Evapotranspiration of irrigation water
LRw = Irrigation water required for salt leaching
FP = Irrigation water required for frost protection
DU = Distribution uniformity
TF = Timing Factor

The energy requirement per volume pumped on-farm (KWh/AF) was estimated based on static groundwater water level, average drawdown, column loss, discharge pressure, and pump efficiency in each zone (see the table below). The average drawdown and column loss information was the same information used to calculate district groundwater pumping and was obtained through pump company interviews conducted by ITRC. The average pump efficiency was obtained from the CEC Agricultural Peak Load Reduction Program On-Farm Pump Testing Database. More information on on-farm overall pumping plant efficiency can be found in **Attachment D**. The total dynamic head (TDH) is calculated based on the static water level, drawdown, column loss, and a discharge pressure. Average static water level values for each zone were obtained from DWR groundwater data and contour maps.

The total volume of groundwater pumped for each irrigation method was calculated based on the volume of water per acre requirement and the irrigation type acreage in each zone.

Multiplying the total volume of groundwater pumped by the energy required to pump it (KWh/AF), the total energy use by on-farm groundwater pumping was estimated for each zone. A detailed explanation on the process used to estimate energy use in California from groundwater pumping on-farm can be found in **Attachment B**.

Table 15. On-farm pumping plant data used to calculate the on-farm energy requirement for pumping groundwater

Zone	Pump Depth	Drawdown (ft)	Discharge Pres (ft)	Column Loss (ft)	TDH	Avg. Pumping Efficiency	On Farm GW KWh/AF
1	180	35	9	8	233	48.3	493
3	180	35	9	8	233	48.3	493
4	180	35	9	8	233	48.3	493
6	180	35	9	8	233	54.0	441
8	65	35	9	4	113	40.3	287
9	150	35	9	7	201	56.9	362
10	200	35	9	9	253	50.8	510
12	160	15	9	2	186	52.3	364
12b	164	15	9	2	190	54.5	357
14	138	50	9	5	202	52.7	392
15	263	35	9	3	310	51.9	611
16	216	20	9	3	248	53.2	478
18	100	20	9	5	134	53.2	257

With energy rates soaring in the past few years, a significant portion of on-farm electric pump motors have been replaced with diesel engines. Pump company representatives were interviewed to help quantify the percentage of electric versus non-electric motors used for on-farm pumping throughout the state. Estimates for each zone, as well as a statewide estimate, are shown in the table below. The figure below shows the trend in on-farm pump power sources since 1979. Data from 1979-1998 was obtained from the *USDA National Agriculture Statistics Service Census of Agriculture – Farm and Ranch Irrigation Surveys*. The results of ITRC pump company interviews were added to show the significant increase in non-electric power use for on-farm pumping throughout the state.

Table 16. Current average pump power source by zone. Engines are primarily diesel.

Zone	Percent Electric motors	Percent Engines
1	90	10
3	90	10
4	90	10
6	95	5
8	90	10
9	80	20
10	80	20
12	80	20
13	80	20
14	65	35
15	70	30
16	70	30
18	90	10
Statewide Average	**82**	**18**

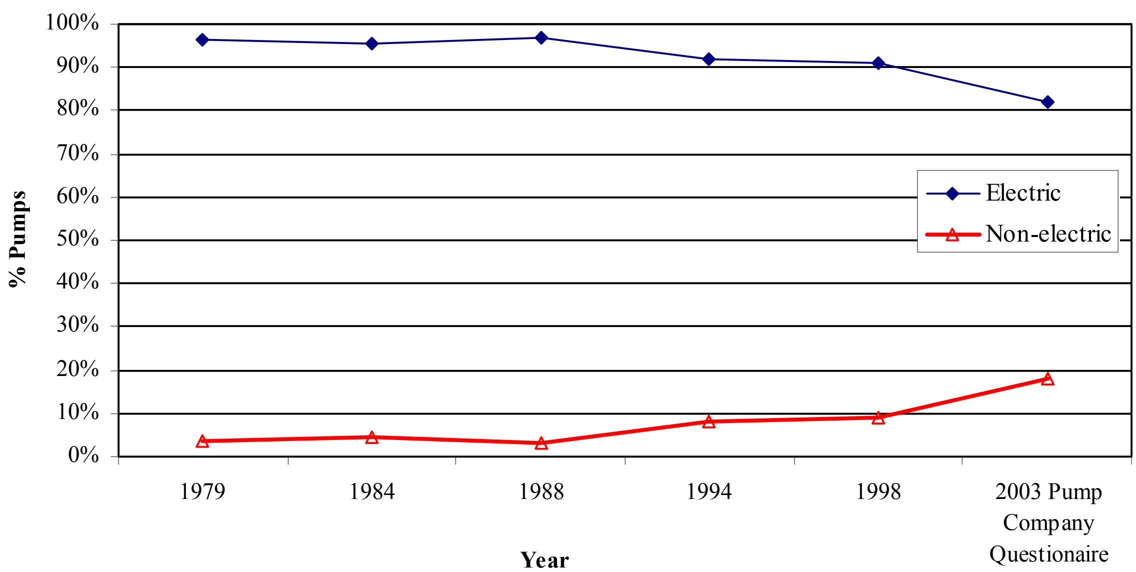


Figure 4. Change in the power source used to operate on-farm pumps in California. 1979-1998 data from USDA Farm and Ranch Irrigation Surveys. 2003 data from ITRC pump company survey.

The notable increase in conversions from electric motors to non-electric engines between 1988 and 1994 is largely due to the demand charge being imposed by the utilities in California.

Table17. Regional and statewide total electric energy required on-farm groundwater pumping.

Modified DWR ETo Zone	On-Farm Groundwater Pumping MWh/Year
1	54,964
3	365,562
4	61,207
6	401,843
8	14,573
9	255,199
10	273,277
12a	283,381
12b	159,637
14	108,394
15	1,659,804
16	846,938
18	14,236
Total	**4,499,000**

On-Farm Booster Pumping

It was assumed that booster pumps are used to increase the pressure of surface water and groundwater for sprinkler and drip/micro irrigation. For sprinkler irrigation, it was assumed that the discharge pressure of the booster pump was 70 psi for row crops and 50 psi for undertree. Drip and microspray irrigation system evaluations conducted throughout the state by ITRC and other agencies were averaged on a regional basis and applied to the appropriate ETo zones. Pump efficiencies were assumed to be the same as the ETo zone average on-farm groundwater overall pumping plant efficiency from the On-farm Pump Testing Database. A detailed explanation of how on-farm booster pump energy use was estimated can be found in **Attachment B**.

Table 18. Average discharge pressure of drip/microspray irrigation methods throughout California

DWR ETo Zone	Drip/Micro Discharge Pres. PSI
1	44
3	55
4	44
6	44
8	45
9	50
10	45
12	38
13	34
14	45
15	42
16	40
18	48

On the Westside of the San Joaquin Valley, surface irrigation methods using tailwater and gated pipe require booster pumps. An estimate of 3 psi was used to calculate this energy requirement – which definitely under-estimates the pressure requirement in some fields, but is quite representative in others. Good data on tailwater pumping requirements is lacking.

Knowing the TDH and average pump efficiency, the energy requirement per volume of water pumped was calculated (KWh/AF). The total applied volume of water for sprinkler irrigation and drip/micro was multiplied by the KWh/AF requirement to obtain energy usage.

Table 19. Regional and statewide electric energy required for on-farm booster pumping.

Modified DWR ETo Zone	On-Farm Booster Pumping MWh/Year
1	20,852
3	145,076
4	18,132
6	148,034
8	21,350
9	87,567
10	58,730
12a	300,329
12b	101,075
14	488,733
15	688,121
16	380,371
18	415,152
Total	**2,873,500**

Orange Cove Irrigation District
Peak Load Reduction Case Study

Site

Orange Cove Irrigation District is located in Fresno and Tulare Counties, approximately 30 miles southeast of Fresno and 20 miles north of the City of Visalia. The Friant-Kern Canal is the District's main source of water to supply 28,000 acres of farmland.

Problem

Parts of Orange Cove Irrigation District's system were not connected to a supervisory control and data acquisition (SCADA) system, which is necessary to enable farmers to shut off pumps during peak periods. Shutting off pumps would allow both the district and individual farmers to curtail peak load, a major priority because of the dramatic increase in power cost.

Solution

OCID took advantage of the CEC Agricultural Peak Load Reduction Program (APLRP) administered by the Irrigation Training and Research Center to help pay for two projects that would help the District and district water users to reduce their peak energy use. To reduce peak load, remote monitoring, measurement, and control components were installed for sections of the water distribution system not currently equipped. The equipment provided the agency with the capability to monitor load, flow, and pumping efficiency in real time, as well as remotely control the operation of each pump station. In addition, two distribution systems were controlled to respond to critical water levels in their respective reservoirs so that pumps can be turned off during the peak period and water users can be supplied by the reservoir uphill. The pumps would only operate during the peak period if the water level in the reservoir dropped below a critical level.

The District reprogrammed the pump activation process so that the most efficient pumps would run the majority of the operational hours and the least efficient pumps would run the least number of hours, thereby increasing the overall pump station efficiency.

OCID also instituted a landowner load reduction program, whereby individual growers signed up with the District to commit to a kW reduction during the peak period. In return, the District reduced the price of water for those growers. Automated on-off valves were installed by the District at the participating farmers' turnouts to automatically stop and start delivery of water during the peak period.

OCID turnout to a farm with an automatic on-off valve installed by the District

Benefits

The State of California, OCID water users, and the District have benefited from these projects. The District can concentrate its pumping during the non-peak period, lowering its overall power costs and passing the savings directly to the farmers. Participating water users receive a substantial break on their water bill as well as their booster pump energy bill. Currently, 815 kW of peak load are being curtailed in OCID boundaries.

Conveyance to Districts

Water conveyed to water districts, particularly on the West and Southern areas of the San Joaquin Valley, requires a certain amount of pumping. Major pumping facilities are located on the California Aqueduct and the Delta Mendota Canal. Data from the California DWR and the Bureau of Reclamation was used to analyze the energy requirement for delivering water to districts.

The majority of pumping occurs on the California Aqueduct from the Delta to Southern California. Pumping into the Delta Mendota Canal is also an important component. Data from the *State Water Project Annual Report of Operations 1997* was used to estimate agricultural pumping requirements in the California Aqueduct and the Delta-Mendota Canal. Municipal and industrial (M&I) water was not included in the energy use component.

Gianelli Pumping\Generation Plant pumps water to the San Luis Reservoir and generates electricity as water is released back to the California Aqueduct. The MWh/AF requirement is the difference between the pumping and generation MWh/AF values. This includes a factor for water lost after pumping (evaporation and seepage).

Table 20. Estimated agricultural pumping on the DMC and the California Aqueduct and the energy required at each pump station

California Aqueduct	**MWh/AF**	**Total Pumped (AF)**	**Ag Water Pumped (AF)**	**MWh for Ag Water Pumping**
Banks Pumping Plant	0.28	2,544,686	1,603,294	450,526
Gianelli Pumping\Generation	0.05	1,774,467	1,774,467	79,851
Dos Amigos Pumping Plant	0.13	3,580,709	2,639,317	353,668
Buena Vista Pumping Plant	0.24	1,154,799	248,407	60,675
Teerink Pumping Plant	0.26	1,042,703	136,311	36,054
Chrisman Pumping Plant	0.62	993,686	87,294	53,901
Edmonston Pumping Plant	2.26	961,114	54,722	123,666
Delta-Mendota Canal				
Tracy Pumping Plant	0.60		869,917	526,125
O'Neill Pumping Plant	0.07		481,117	35,122
			Total	**1,719,588**

It should be noted that these State Water Project facilities are operated during non-peak hours to reduce peak energy charges and California's peak energy demands. However, deliveries to irrigation districts are made 24 hours a day. The SWP utilizes existing surface storage facilities as well as pool storage to accomplish this.

Some smaller pumping plants that pump primarily M&I water have not been included. Other than at the Gianelli plant, the values for MWh/AF do not include the amount of generation that occurs as the water is released from storage reservoirs. For example, the amount of pumping energy required to move water from the Delta to the Metropolitan Water District of

Southern California (MWD of SC) is 3.85 MWh/AF (sum of MWh/AF along the California Aqueduct). But there is approximately 0.8-0.9 MWh/AF of generation capability from the Edmonston Pumping Plant before the water reaches Los Angeles (this depends on the direction that the water is taken, east or west). Therefore, the total energy used is a gross value, as are the other values calculated for energy use by agricultural pumping. MWD uses an estimate of approximately 3.0 MWh/AF (3000 KWh/AF) as the net energy requirement to move water from the Delta to Southern California through State Water Project facilities.

Current Water Transfers with a Significant Impact on Energy

Water transfers occur between irrigation districts and between districts and the environment every year. One district will transfer excess water to another district for direct payment or the ability to obtain water in the future when a deficit occurs. The analysis of energy use for conveyance to districts takes this into account as a "snapshot" when analyzing the deliveries to each agricultural water agency along the California Aqueduct and the Delta-Mendota Canal.

As pointed out earlier, the energy use estimated in this report does not account for energy use from pumping of municipal and industrial (M&I) water anywhere in California. However, as part of this report, ITRC analyzed how transfers between agriculture and M&I might impact future energy demands. Possible scenarios are outlined in the Future Potential Energy Requirement section of this report. The following will provide a short background to current water transfers from agriculture to M&I.

Throughout the years there have been a number of transfers from agriculture to urban sectors. The transfers that have the most significant impact on energy use are to Metropolitan Water District of Southern California because of the significant level of pumping required to get water to Southern California. Other water transfers from agriculture to M&I are occurring along the coastal regions. However, in comparison, the energy use is not as significant and because of time constraints will not be discussed in any detail. To assist readers with understanding more about the movement of water to southern California, Attachment J is provided.

Currently, Metropolitan Water District of Southern California (MWD) has transfer agreements with different agricultural water users for Colorado River water, as shown below:

Table 21. Current water transfer agreements between Lower Colorado River Basin agricultural water agencies and MWD of So. Calif.

District	Status	AF/Year	MWh/AF	Total MWh
IID	In Place	105,000	2.18	230,000
PVID	Pending	25,000 to 111,000	2.07	52,000 to 230,000
CVWD	In Place	60,000	NA	NA

IID - Imperial Irrigation District
PVID - Palo Verde Irrigation District
CVWD - Coachella Valley Water District

The Imperial Irrigation District (IID) agreement was signed in 1990 and fully implemented by 1998. The Palo Verde Irrigation District (PVID) Agreement has been tentatively approved but must await approval of the QSA (Qualification Settlement Agreement) currently being negotiated. If the QSA were to be finalized, the PVID transfer could occur within a few months. The Coachella Valley Water District (CVWD) agreement is in reality an exchange, not a transfer. It involves exchanging water that CVWD is entitled to, and has paid for, from the California Aqueduct with Colorado River water that MWD is entitled to. This is essentially a bucket for bucket exchange.

The MWD also has transfer agreements with agricultural water users in the northern portion of the state. In 2003, MWD exercised one-year options for transfer agreements with districts in the Sacramento Valley. Some water users in these districts have agreed to fallow land that is typically used for growing rice. MWD pays the farmers for the water the crop would have used (evapotranspiration of irrigation water) and that water amount is transferred to MWD. MWD pays the farmers $10 per acre-foot for the option to take water; when MWD exercises the option, it pays the farmer an additional $90 per acre-foot (MWD, 2003).

Table 22. Options exercised by MWD to transfer water from northern California to southern California (MWD, 2003)

Water Agency	Amount of Water Transferred (AF)
Glenn-Colusa Irrigation District	50,000
Western Canal Water District	20,000
Richvale Irrigation District	17,200
Meridian Farms Mutual Water Company, Natomas Central Mutual Water Company, Pelger Mutual Water Company, Pleasant Grove-Verona Mutual Water Company, Reclamation District 108, River Garden Farms, Sutter Mutual Water Company	50,000

The table below shows some of the water transfers for fiscal year 2002-2003 through CALFED water agencies. The values on the left indicate contracted quantities and the agencies selling the water. The values to the right indicate actual acquisitions.

Table 23. A list of CALFED water agencies that had water transfers during fiscal year 2002-2003 and the amounts. Courtesy of CALFED.

29-Sep-03

ENVIRONMENTAL WATER ACCOUNT WATER ACQUISTIONS 2002-03 (FISCAL YEAR)							
Contracted Quantities				Actual Acquisitions			
Location/Purchaser	Seller	Amount of Water (AF)	Total Cost	Water Purchased (AF)	Costs	Additonal Option Fees	Total
Upstream of the Delta							
State	Oroville-Wyandotte Irrigation District[1]	10,000	$750,000	4,914	$368,550		$368,550
State	Yuba County Water Agency[1]	185,000	$17,675,000	65,000	$5,525,000		$5,525,000
Total Upstream		195,000	$18,425,000	69,914	$5,893,550		$5,893,550
South of the Delta							
State	Kern County Water Agency	198,240	$33,700,800	125,000	$21,250,000		$21,250,000
State	Santa Clara Valley Water District	30,000	$4,860,000	20,000	$3,240,000		$3,240,000
Total South of Delta		228,240	$38,560,800	145,000	$24,490,000		$24,490,000
Total Upstream and South of Delta		423,240	$56,985,800	214,914	$30,383,550		$30,383,550
Source Shift with MWD		100,000	$2,500,000	0	$0	$500,000	$500,000
Total		523,240	$59,485,800	214,914	$30,383,550	$500,000	$30,883,550

[1]Represents purchase quantities. Does not include losses (including carriage water losses across the Delta).

The amount of energy required to transfer water from Northern California to Southern California varies somewhat depending on what MWD decides to do with it along the way. The obvious track that the water follows is from Northern California into the Delta, where it enters the California Aqueduct and continues on to Southern California. Another option is to "bank" the water in one of the water banking facilities along the California Aqueduct. Water banking is discussed in greater detail later in this report.

Table 24. Energy requirement for water transfer scenarios

Scenarios	Added Energy Component KWh/AF	Total Energy Requirement KWh/AF
Direct transfer from Northern California to MWD	--	3,850*
Banking Options		
Arvin-Edison WSD	1,100**	4,950
Semitropic WSD	650**	4,500
Kern County Water Agency	400**	4,250

*The 3,850 KWh/AF does not account for hydroelectric generation
The explanation of these values can be found in the Water Banking section of this report and in **Attachments G and **H**.

From an energy aspect, there are a number of other issues that should be considered. Recent changes in rules regarding water transfers have made it difficult to directly substitute surface water for groundwater without first storing the water in the aquifer. This was the result of historical impacts on groundwater levels from this type of transfer. If a farmer agrees to forgo surface deliveries so that water can be transferred to another location and instead pumps groundwater to supply the crop, the surrounding farmers are negatively impacted by the decreasing groundwater level but do not receive any type of subsidy from the transfer. Therefore, it is unlikely that transfers without storage in an aquifer will occur in the future unless the "rules" change, and the increased energy requirement for the farmer's groundwater pumping will not result.

Many districts in the Sacramento Valley pump from rivers to supply their water. This has not been taken into account in the energy requirement values in the table above. Therefore, the energy requirements listed in the table above will be somewhat lower than actual. However, since the lift is relatively low from the river to the distribution system, the energy savings are insignificant compared to the energy requirement to send the water to southern California. ITRC estimates that the average pumping requirement of surface water by irrigation districts is 16 KWh/AF in northern California.

POTENTIAL FUTURE ENERGY REQUIREMENTS

The goal of this section it to introduce and describe some current trends, as well as likely future scenarios, that form the basis for quantifying energy requirements.

On-Farm Irrigation – Ideas to Reduce the Volume of Water Applied.

Agricultural applied water is directly proportional to energy use by agricultural water pumping. If the amount of applied water is reduced, in theory the energy use will be reduced. However, in order to reduce the applied water, it may be necessary to actually use more energy. For example, converting from surface irrigation to a drip/microspray irrigation system requires a booster pump. It is also important that the decrease in applied water does not have a significant negative impact on crop yield, either through increased water stress or salt buildup in the rootzone. A number of water management methods are currently used that may or may not impact energy use. Some of the main methods are discussed below.

Conversion to Drip/Microspray Irrigation

Conversion from surface and sprinkler irrigation methods to drip or microspray irrigation has become very popular over the last few decades. In coastal regions, surface row crop drip has become one of the most dominant irrigation methods used on vegetable crops, especially after germination. In the Central Valley, as well as in portions of the Sacramento Valley, drip and microspray irrigation have seen a significant increase in popularity on permanent crops, which is predicted to continue.

From an outsider's perspective it would seem like utilizing drip/micro irrigation should save a significant amount of water. This misconception can be partially attributed to the names given to these irrigation methods: drip, microspray, low volume irrigation, and trickle, as compared to terminology used for surface irrigation, such as flood. The physiological attributes of crops and the understanding of irrigation as a whole are also not understood by most people.

The following is a list of facts about drip/micro irrigation:

- If a well-watered crop transpires 30 inches of water, it will transpire 30 inches regardless of whether drip/micro, sprinkler, or surface irrigation methods are used (assuming the same amount of stress is applied under each method).
- Drip/micro has the potential to provide better uniformity than sprinkler or surface irrigation. However, a well-managed surface irrigation system can have the same distribution uniformity as an average drip/micro system and, conversely, a poorly managed or designed drip/micro system can have a worse distribution uniformity than conventional methods.

– Drip/micro systems are designed to operate much more frequently than surface and sprinkler systems. Since the soil surface is wet more often, the evaporation of irrigation water is higher. An important factor in the amount of evaporation is the fraction of soil surface wetted. The majority of systems being installed in California utilize two drip lines per row of trees with the goal, for both drip and microspray, to have about a 60% wetted fraction. This provides for a larger soil reservoir and enables the tree to utilize more of its root system for water and nutrient uptake.
– The increased management and higher frequency of irrigation associated with drip/micro irrigation leads to less crop water stress, which increases the amount of crop transpiration.
– Maintaining a good distribution uniformity for a drip/micro system requires more management than surface or sprinkler. However, it provides farmers with the ability to inject fertilizers and other chemicals directly into the irrigation system and apply them with a high level of uniformity across the field, which enhances overall crop management.
– For surface row crop drip, one of the major factors attributing to its increased popularity is distribution uniformity, especially in coastal regions where wind and uneven terrain are significant factors. Traditionally, sprinklers were used in these situations. Wind has a significant effect on sprinkler distribution uniformity.

More information on evaporation and transpiration from drip/micro irrigation can be found in *Evaporation from Irrigated Agriculture Land in California* (Burt et al., 2002). The following is an example of energy use for drip/micro compared to surface irrigation.

Example – Conversion from surface irrigation to drip/microspray on almonds in ETo Zone 15

This example analyzes crop applied water use and the energy requirement for almonds converted from surface irrigation to drip/microspray. The evapotranspiration of irrigation water (ETirr) plus the leaching requirement water (LRw) values can be found in tables located in **Attachment B**. The distribution uniformity (DU) values are the same as those used to calculate regional applied water and are also described in **Attachment B**. **Case – 1**. It is assumed that the amount of irrigation water delivered by the local irrigation district per acre will not change because of the conversion to drip/micro. On-farm groundwater pumping will make up the difference between applied water and district groundwater and surface water deliveries. **Case – 2.** It is assumed that the farmer will use only on-farm groundwater pumping to supply the drip/micro system.

<u>Given</u>

Surface Irrigation

ETirr+LRw	3.26	AF/acre
Distribution Uniformity	0.70	
Booster Pump Energy Req.	14	KWh/AF

Drip/Micro Irrigation

ETirr+LRw	3.68	AF/acre
Distribution Uniformity	0.80	

Booster Pump Energy Req.	191	KWh/AF

District water supplies

District Surface water	1.93	AF/Acre
District Groundwater	0.23	AF/Acre

District water supply energy requirement

District Surface water	123	KWh/AF
District Groundwater	394	KWh/AF

On-farm groundwater energy requirement	611	KWh/AF

Results

Surface Irrigation

Applied Water

Total applied water	(ETirr+LRw)/DU
Total applied water	(3.26 AF/Acre)/0.70
Total applied water for surface irrigation	4.66 AF/Acre

Sources and amounts of applied water

District surface water	1.93	AF/Acre
District groundwater	0.23	AF/Acre
On-farm groundwater	2.50	AF/Acre

Energy required

Amount of energy required per acre (KWh/Acre) = (AF/Acre) * (KWh/AF)

Sources and amounts of energy required

District surface water	237	KWh/Acre
District groundwater	91	KWh/Acre
On-farm groundwater	1,526	KWh/Acre
Booster pump	65.2	KWh/Acre
Total energy required for surface irrigation	**1,919**	**KWh/Acre**

Drip/Micro Irrigation – Case 1 (surface water used)

Applied Water

Total applied water	(ETirr+LRw)/DU
Total applied water	(3.68AF/Acre)/0.80
Total applied water for drip/micro irrigation	4.60 AF/Acre

Sources and amounts of applied water

District surface water	1.93	AF/Acre
District groundwater	0.23	AF/Acre
On-farm groundwater	2.44	AF/Acre

Energy required

Amount of energy required per acre (KWh/Acre) = (AF/Acre) * (KWh/AF)

Sources and amounts of energy required

District surface water	237	KWh/Acre
District groundwater	91	KWh/Acre
On-farm groundwater	1,491	KWh/Acre
Booster pump	879	KWh/Acre

Total energy required for drip/micro irrigation 2,697 KWh/Acre
(assumes surface irrigation water will be used)

Overall the amount of energy use is higher for drip/micro because of the need for booster pumping. There is some energy savings in on-farm groundwater pumping but it is relatively insignificant because the actual savings in applied water from the conversion to drip/micro was only 0.04 AF/acre. This water savings is due to the improvement of the distribution uniformity and results in an energy savings because the 0.04 AF/acre no longer has to be supplied through on-farm groundwater pumping.

However, there is a completely different perspective if one considers that in most irrigation districts, farmers will opt to use well water rather than surface water if they switch to drip irrigation. This is because (a) they have the water available "on demand", and (b) the water is generally cleaner, and requires less filtration than does surface water.

Drip/Micro Irrigation – Case 2 (well water only is used)

Applied Water

Total applied water (ETirr+LRw)/DU

Total applied water (3.68AF/Acre)/0.80

Total applied water for drip/micro irrigation 4.60 AF/Acre

Sources and amounts of applied water

On-farm groundwater	4.60	AF/Acre

Energy required

Amount of energy required per acre (KWh/Acre) = (AF/Acre) * (KWh/AF)

Sources and amounts of energy required

On-farm groundwater	2811	KWh/Acre
Booster pump	879	KWh/Acre

Total energy required for drip/micro irrigation 3,690 KWh/Acre
(assuming all irrigation water comes from groundwater)

The energy requirement per acre increases significantly under this scenario (2,697-3,690 KWh/Acre). In order to analyze what would happen on a regional basis ITRC conducted an analysis where drip/micro acreage doubled in each region throughout California. The majority of the acreage converted was from surface irrigation (80%). The remaining 20% was converted from sprinkler (10%) and sprinkler/surface combination (10%).

In certain regions, farmers are likely to shift completely to groundwater with the conversion to drip/micro because of irrigation district inflexibilities and increasing filtration requirements associated with surface water. The table below indicates the estimated percent of drip/micro systems that will use either on-farm groundwater only or district surface water and some groundwater. The impact on groundwater levels will be significant. It was assumed that groundwater levels would drop by 20 feet throughout most of the state. The drop in groundwater is caused by less recharge from surface water, and more withdrawals.

Table 25. Percent of future drip/microspray irrigation systems that will likely utilize only groundwater from on-farm pumping.

Modified ETo Zone	Increase in Drip/Micro Acreage by Region	Percent of Future Drip/Micro Systems using On-Farm Groundwater Only	Percent of Future Drip/Micro Systems using District Surface Water and On-Farm Groundwater
1	7,641	100%	0%
3	68,903	100%	0%
4	18,709	100%	0%
6	93,515	100%	0%
8	29,200	100%	0%
9	82,773	50%	50%
10	32,225	100%	0%
12a	319,024	67%	33%
12b	101,262	95%	5%
14	365,207	67%	33%
15	434,750	50%	50%
16	198,189	50%	50%
18	60,222	5%	95%

Regionally, the energy requirement will increase significantly with the shift to using groundwater, opposed to district surface water with groundwater as a supplement. The table below shows the increase in energy on a regional basis with a doubling in drip/micro acreage with the assumptions stated above.

Table 26. Future electric energy requirement with a doubling in drip/micro acreage throughout California by region.

DWR ETo Zone	Irrig. District Surface Water Pumping	Irrig. District Groundwater Pumping	On-Farm Groundwater Pumping	On-Farm Booster Pumping	Conveyance to Irrig. Districts	Total Electric Energy Use by Zone
	MWh/Year	MWh/Year	MWh/Year	MWh/Year	MWh/Year	MWh/Year
1	0	0	53,835	23,053		76,889
3	0	0	355,053	172,310		527,362
4	0	0	56,504	24,842		81,346
6	0	0	369,899	171,295		541,194
8	3,896	137	14,282	44,777		63,091
9	0	0	237,094	119,989		357,082
10	0	0	270,699	72,199		342,899
12a	26,171	27,051	502,237	559,400		1,114,859
12b	8,307	8,586	248,337	190,200		455,431
14	131,125	2,032	306,254	762,535	450,526	1,652,471
15	514,605	199,386	1,887,797	965,421	1,269,062	4,836,272
16	137,662	8,840	894,352	493,252		1,534,105
18	0	0	13,505	480,644		494,149
Total	**821,800**	**246,000**	**5,209,800**	**4,079,900**	**1,719,600**	

Total Ag. Irrig. Water Electrical Energy Usage	**12,077,100**	**MWh/Year**
Increase in Electrical Energy Usage:	**1,917,200**	**MWh/Year**

The annual electric energy required for agricultural pumping increases by nearly 2 million megawatt hours per year. The irrigation district surface and groundwater pumping remains the same – an assumption that does not have a large impact on the final value due to the geographic location of this district, but which could be challenged. However, there is a significant increase in the energy required for on-farm groundwater and booster pumping.

In our assumptions, the total annual applied (not net) water statewide increased from 36,230,300 AF to 39,574,400 AF because of the increase in groundwater pumping. If this scenario occurs, the 3+ million acre-feet of water will show up as surplus by irrigation districts in California. How this surplus will be used is unknown. It could be transferred, used for groundwater recharge, applied to normally fallow land, or used for environmental restoration. In the end, however, unless the groundwater overdraft is addressed, this represents a serious challenge to sustainable irrigation in California.

Regulated Deficit Irrigation (RDI)

Regulated deficit irrigation (RDI) is primarily used in California to enhance the quality of harvested crops. Basically, RDI is a practice of purposely irrigating less than the crop requires to induce crop water stress. As a result, the crop uses less water than it would if it were fully irrigated. Currently, wine grapes, cotton, and processing tomatoes are important crops for which most farmers deliberately apply RDI for improved crop quality.

Ongoing studies throughout the world are aimed at determining what times of the year RDI is most effective and how much stress the crop should undergo. Studies in California have primarily focused on the use of RDI for orchard and vineyard crops as well as select field crops. One of the reasons RDI has gathered so much attention is the possibility of reducing applied water significantly during a drought period when water supplies are limited. Results have indicated a minimal yield loss with as much as a 50% reduction in applied water the same year (applied water is based on irrigation scheduling using crop evapotranspiration estimates). However, long-term studies have shown that significant crop stress over multiple years can have a significant impact on future yields.

The fact that RDI can for some crops reduce evapotranspiration with little or no significant yield loss – and possibly even increase crop quality, – is of course attractive. The real question comes when estimating the potential savings due to RDI in California, where many farmers are already using RDI without realizing it. ITRC irrigation evaluations performed for the USBR and Westlands Water District have shown that many drip/micro fields throughout California are irrigated with excessive durations but not as frequently as they should be. This leads to crop water stress between irrigations. If crop water stress is already occurring and the actual crop evapotranspiration is less than it could be, how much of an effect will RDI have? If farmers are told to apply 75% of what they are currently applying and they are already applying 80% of what is needed for full crop evapotranspiration, their yields, especially in future years, will be negatively impacted.

The question that needs to be addressed regarding RDI and water savings is: where are farmers right now with regards to actual crop water use versus potential crop water use? It is probable that most farmers throughout California are already deficit irrigating at some level.

Irrigation Scheduling

Irrigation scheduling has been the focus of water conservation for many decades. Utilizing local weather parameters either through weather stations or evaporation pans and incorporating that information with actual field soil moisture data can be useful when determining when to schedule irrigations. Current standards use local specialized weather stations to calculate grass reference evapotranspiration. A crop coefficient or sets of crop coefficients are used to estimate the actual or predicted crop evapotranspiration. Models are often used to correct crop coefficients based on crop stress and evaporation (the FAO 56 Dual Crop Coefficient is a good example). Once crop water use has been calculated, an irrigation schedule can be created and often field soil moisture sensors are used as a check.

Applying water when it is needed can reduce the potential for over- or under-irrigation. Timely application can result in reduced water loss to deep percolation from over-irrigation and <u>increased</u> water use by the crop from less stress associated with under-irrigation. The crop utilizes more applied water; however, the overall change in applied water due to irrigation scheduling may not be significant.

Groundwater Banking

Groundwater banking involves the use of an aquifer for water storage by banking partners who are not overlying landowners and who have not traditionally used the aquifer. At some future date, the banking partners would be able to withdraw (called "Take") the water they put into the aquifer (minus any losses). In California, the average annual runoff exceeds the available surface storage and existing aquifer recharge ability. Groundwater banking is one method to increase the aquifer recharge and "capture" some of the excess runoff that otherwise would not be available for urban, agriculture or environmental purposes. A glossary of groundwater banking terms can be found in **Attachment H**.

Groundwater banking has physical, legal, and economic characteristics that are different and less clearly defined than surface storage systems (reservoirs). Nevertheless, the need for additional storage and the difficulties of building new surface storage has encouraged the development of groundwater banking. The physical, legal, and economic hurdles are being addressed and groundwater banking projects are moving from the drawing board to implementation. One thing that is apparent is that there is no one groundwater banking model that fits all situations. Since the physical, legal, and economic conditions vary sufficiently from region to region, a customized program may be needed for each project.

This analysis is primarily interested in the energy component of a groundwater banking program. It will examine the energy required for basic operation of the groundwater banks and compare that to the energy savings realized from a higher water table. Three case studies in the southern San Joaquin Valley were used to analyze the effects on energy use of groundwater banking:

1. Arvin-Edison Water Storage District (Arvin-Edison WSD)
2. Kern County Water Agency (KCWA)
3. Semitropic Water Storage District (Semitropic WSD)

Detailed case studies for these three agencies can be found in **Attachment F**.

Basic Operation

The basic purpose of a groundwater banking project is to store a given volume of water in an aquifer and return the water at some time in the future. An energy analysis of the basic operation is to quantify the energy required for "Put" and "Take". "Put" energy is the energy required to bring in surface water from an outside source to the project area and store the water in the groundwater bank's aquifer. "Take" energy is the energy required to lift the water out of the aquifer and return it to the elevation it was originally at before it was brought in to the project area. The sum of the energy required for the put and take is the <u>additional</u> energy component required that the banking partner would not be subject to if the water was transported directly from the source to the end user.

It should be noted that "Put" energy will mainly occur in wet years and "Take" energy will mainly occur in dry years. This is because a wet year is when excess water is available for banking partners to purchase but is not needed for their operations. Conversely, the banking partners would have a higher need to "Take" water to meet their operational needs during dry years. The result is that describing the additional energy required per unit of water as the sum of "Put" and "Take" in a groundwater banking program does not reflect the seasonal or even yearly effects on energy use.

The additional energy component for the three case studies is shown in the figure below:

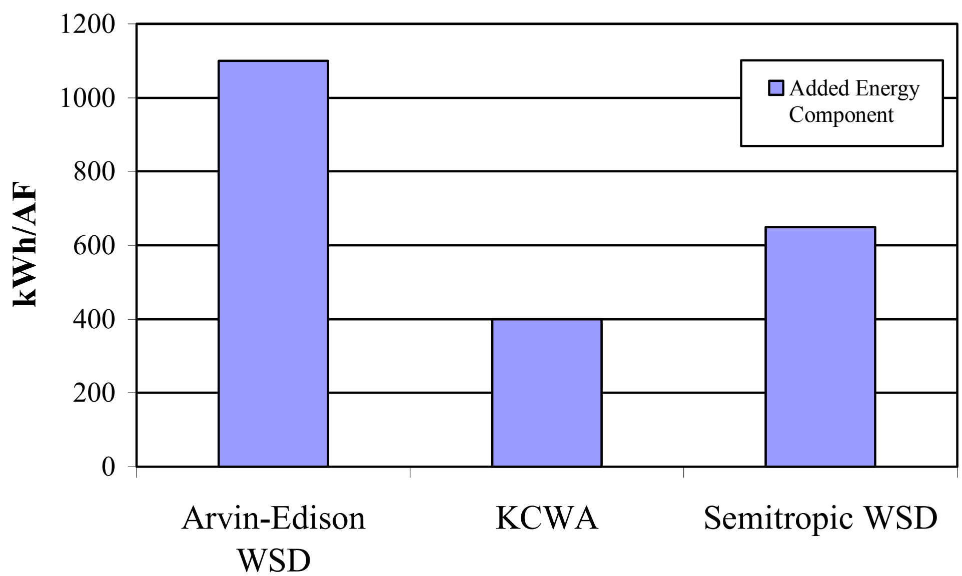


Figure 5. The added energy required for the basic operation of the three case studies

The added energy component for water that is actually physically pumped out of the ground and returned to the banking partner is approximately 400 KWh/AF for KCWA, 650 KWh/AF for Semitropic WSD and 1,100 KWh/AF for Arvin-Edison WSD. This would be the energy required for a bucket-for-bucket exchange of water from the groundwater bank. In lieu exchanges may have a energy requirement if there is additional pumping required to return the water after the water is pumped to the surface; however, it is generally lower than normal banking operations because the "Put" energy is not needed.

The Arvin-Edison WSD primarily uses active recharge for its groundwater banking program with the Metropolitan Water District (MWD), its main client. KCWA also primarily uses active recharge and is the primary wholesaler for State Water Project (SWP) water for Kern County. Semitropic WSD primarily uses the in-lieu method to operate its groundwater banking project.

There are generally some infrastructure additions or improvements needed for each of these groundwater banking programs. Arvin-Edison WSD, for example, increased the size and number of spreading basins and the number of wells as well as constructed a pipeline and pumping plant to enable the return of groundwater back to the California Aqueduct. KCWA's groundwater banking programs generally involve having the control of the overlying land and the maintenance of the corresponding well fields. Semitropic WSD was essentially a groundwater region prior to the banking project so, in order to develop a conjunctive use arrangement for their in-lieu groundwater banking program, it needed to add infrastructure to bring surface water to the farmers' fields.

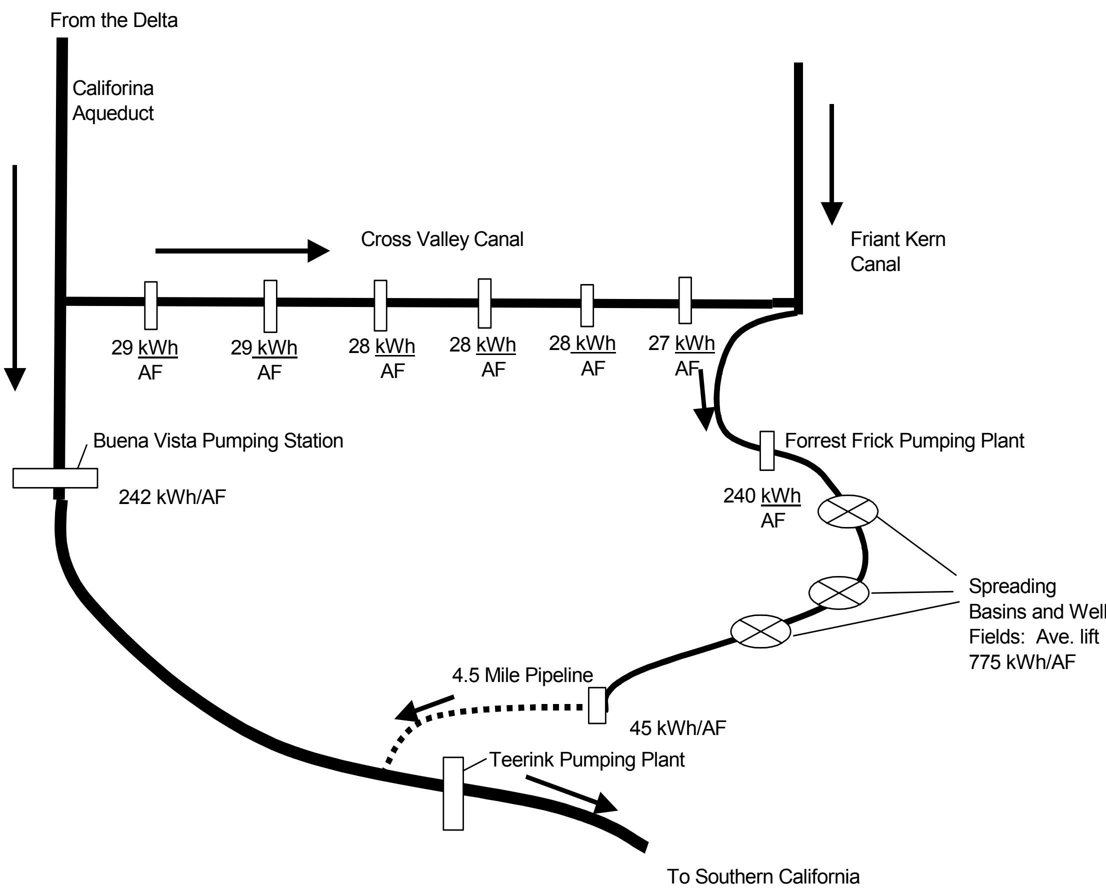


Figure 6. General schematic of how water banking is accomplished in Arvin-Edison WSD.

Raising the Water Level in the Aquifer

In all three cases, the groundwater banking program has raised the groundwater level above what it would have been without the groundwater banking program. This benefits both overlying landowners and adjacent landowners who are affected by the groundwater gradient within the groundwater banking project area.

A comparison of the energy required for basic operation (energy cost) of the Arvin-Edison WSD groundwater banking project with MWD, with the potential energy savings from a raised water table is shown in **Attachment G**. The result of this comparison is shown in the figure below.

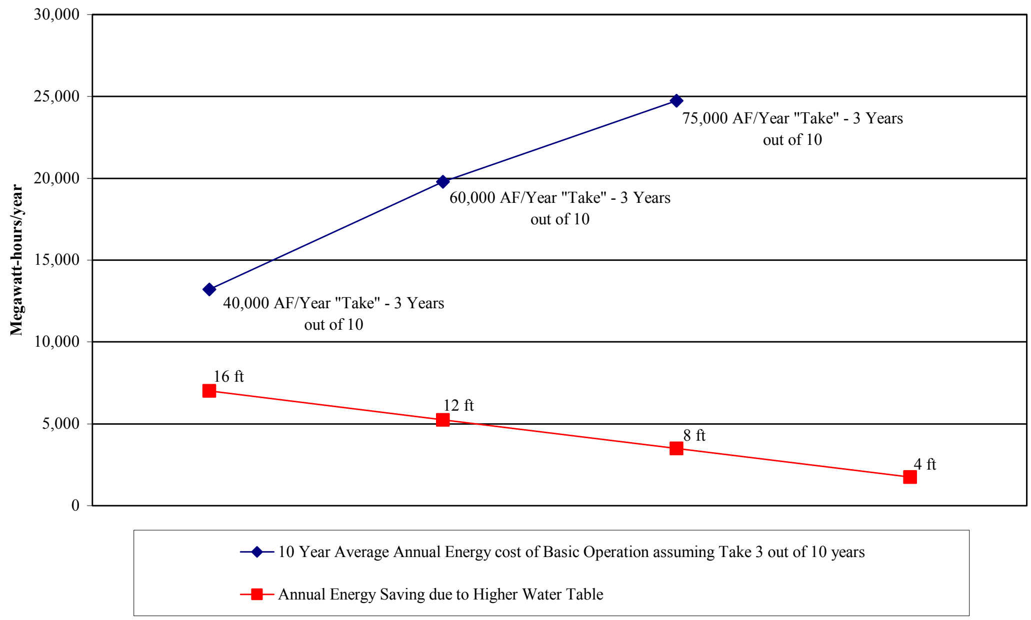


Figure 7. The relationship of energy cost/savings for Arvin-Edison WSD. The energy savings is seen every year where the energy cost is spread out, assuming three years of "take" out of 10 years.

The figure above indicates that, overall, 2-10 times more energy is required to operate the groundwater banking program with MWD than is saved because of the increase in water level. However, the overall benefit to each party outweighs the energy requirement. If the banking program between Arvin-Edison WSD and MWD did not take place, Arvin-Edison WSD groundwater users would not have any benefit from a higher groundwater level and MWD would not have the ability to store surplus water for times when there is a shortage. In effect, MWD would lose that water.

Electrical Energy Time of Use Effects

The electrical energy required to "Take" water from a groundwater banking program is not only a function of the total pumping energy required but also when that energy is required. The timing of when a "Take" occurs might have some implications for reducing peak energy loads. The benefit of such timing might be measurable not only for daily peak energy but seasonal peak energy as well.

The higher water table due to a groundwater banking program discussed in the previous section would also have an effect on peak energy requirements. For the Arvin-Edison WSD example, if the water table were to be raised 16 ft due to the groundwater banking program, assuming the pumps run continuously for 4 months from May to September, there would be a peak load reduction of 2.4 megawatts (MW).

The effect on peak load could be higher or lower than 2.4, depending on current irrigation management practices and crop water demand. The peak reduction would be less than 2.4 MW if a certain percentage of the current and historical irrigation practices were to avoid peak periods (off-peak use only). Since the peak load reduction estimate of 2.4 MW is an average over the entire peak period (May – September), the actual peak load reduction during June, July, and August (when more water is pumped because of higher ET rates) would be greater than this estimate. This would correspond to high peak loads due to the demand for air conditioning.

The three groundwater banking programs reviewed were set up so that in no case will the program adversely impact overlying landowners or even adjacent landowners who are hydraulically connected to the aquifer. For instance, Arvin-Edison WSD has an agreement with its major banking partner, MWD, that MDW can "Take" water only when it doesn't adversely affect the farmers in the district. This essentially means that MDW would be unable to "Take" water during the peak irrigation season, since all of Arvin-Edison WSD facilities will be needed to meet irrigation demand. If it is assumed that annual peak loads occur during the summer, which coincides with peak irrigation demand, further investigation might show that there is a benefit to peak energy reduction when a groundwater banking program can be used to shift water transfers from summer to other times.

Groundwater Banking Summary

- Groundwater banking projects have become an accepted method for storing water during surplus years for use during dry years.
- Groundwater banking projects will increase throughout the state of California as the demand for water for urban, agriculture and environmental use increases.
- Groundwater banking projects can have a significant added energy component per unit of water compared to surface storage (reservoirs).
- Groundwater banking projects may lower the energy requirement for normal groundwater pumping activities of the overlying landowners up until the banking partners' withdrawal all of their entitled groundwater.
- The potential energy required for the annual average "Put" and "Take" by the banking partners is significantly higher than the potential benefit of a lower energy requirement due to a higher water table from the banked water.
- If the "Put" energy requirement is significant, in-lieu projects will require less energy.
- There may be potential to reduce peak electrical energy requirements by having groundwater banking projects.

Impacts from Future Water Transfers

Water transfer refers to the shifting of water from one region to another. There are a number of possible scenarios that would affect future energy demands. Some of the possibilities and future plans are discussed below. The predicted energy use resulting from these scenarios is shown in the **Executive Summary**.

Exchange Contractors can purchase water from one region and sell it to another. This generally involves farmers in water-rich areas in Northern and Central California selling water they are entitled to through their irrigation district to water-short areas to the south. The energy component involved would be the pumping requirement to lift the water up into the California Aqueduct. For this scenario, the exchange is assumed to come from farmers entitled to water from the Delta-Mendota Canal to farmers who are in districts fed by the California Aqueduct in the Southern San Joaquin Valley.

The second scenario is for the proposed exchange of water from Northern California to farmers and metropolitan users to the south. The energy component of this scenario is the energy expended to get this water to Southern California plus the potential energy required for groundwater pumping by Northern California farmers who will not receive surface water under this scenario.

San Diego County Water Authority and Imperial Irrigation District have a water transfer agreement where water would be taken from the Colorado River above Parker Dam through the Colorado River Aqueduct and delivered to SDCWA through MWD of SC facilities. The water that is transferred would need to be pumped into the Colorado River Aqueduct. This creates a pumping demand as well as a loss of potential energy generation at Parker Dam and in the All-American Canal.

Urbanization

Urban sprawl into agricultural areas is occurring throughout California. A recent UC Agricultural Issues Center (AIC) study reported that 497,000 farmland acres were converted to urban uses between 1988 and 1998, as population rose by 5.4 million (19%). This translates to the development of 0.1 acres of farmland, on average, for each new resident (Gomes, 2002). Much of this expansion is occurring in the Sacramento and San Joaquin Valleys south of Sutter County. Land around metropolitan areas that is being converted to urban uses is generally prime irrigated agricultural. Irrigated agriculture is shifting to less desirable land away from metropolitan areas. This is shown in the figure below.

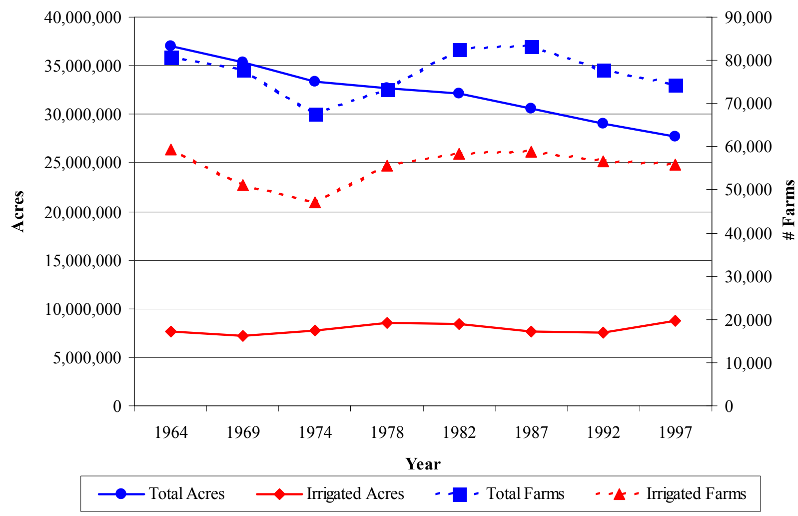


Figure 8. Trends in California's agricultural acreage and farm numbers (1964-1997) (*1998 Farm & Ranch Irrigation Survey - Census of Agriculture*, USDA)

Overall, the amount of agricultural land in California has decreased dramatically since 1964. However, the amount of irrigated agriculture has not changed significantly. This is due to the conversion of lower quality, previously non-irrigated land to irrigated agriculture.

The difference in the amounts of applied water used by urban compared to agriculture is not significant. The California Department of Water Resources has found that urban applied water use is 3.2 acre-feet per acre per year in Fresno, California (*DWR Bulletin 160-98*). The table below compares this use to typical DWR estimated agricultural applied water use for the Fresno region (the estimated water use in the table below are DWR estimates and were <u>not</u> used elsewhere in this report).

Table 27. Urban applied water use estimate compared to typical applied water use by crops in the Fresno area

Type of Use	Annual Applied Water Use (Acre-Feet/Acre)
Urban	**3.2**
Agricultural	
Barley	**1.3**
Grapes	**2.9**
Cotton	**3.2**
Deciduous Orchard	**3.5**
Pasture	**4.5**
Alfalfa	**4.7**

(*California Department of Water Resources Bulletin 160-98*)

However, the energy required for urban applied water is typically much greater than for agriculture. Typically the source of water for urban use is groundwater or treated surface water. Both require significant energy requirements. The actual energy required for urban water is beyond the scope of this report. However, it is important to understand that the effect of urbanization on water demands is negligible and its effect on energy demands is significant.

Ranchettes

In recent years, a popular form of urbanization is for developers to buy large parcels of land and split them into 0.5- to 8-acre lots. Generally, a single-family dwelling is built on these relatively large lots and they are termed "ranchettes." The popularity of ranchettes has increased in suburban areas where the price of land is reasonable. Most of the owners commute to the cities for work and recreation but do not feel they live in the confined areas generally associated with urban or suburban housing.

Unlike complete urbanization of a region where lots can be a quarter to an eighth of an acre or smaller, ranchette areas are open and can be used for hobby farming, to raise horses, etc. The amount of area currently in ranchettes has not yet been defined; however, the California Department of Conservation Division of Land Resource Protection Farmland Mapping and Monitoring Program is currently completing a survey of Fresno, Madera, Merced, and Stanislaus counties as a pilot project to begin defining this area. Other important questions that must be addressed are:

1. How is the conversion to ranchettes from irrigated agriculture going to affect the amount of applied water?
2. What is the source of the water, and is it different than the source of the irrigated agriculture that it replaced?

3. How will the answers to the first two question impact energy requirements?

To help answer the first question, ITRC analyzed LandSat 7 satellite images and Department of Water Resources Land Use Survey shapefiles for four counties in California. The DWR does not have a specific category for ranchettes; however, they do have a category that groups ranchettes and residential areas that comprise relatively large lots that do not fall into the urban category. This category is abbreviated UR. For the ITRC analysis, the vegetative index calculated from the LandSat images was used to estimate the amount of irrigated vegetation in the UR category. A detailed explanation of the process used can be found in **Attachment E**. The table below shows the results of the evaluation.

Table 28. Percent of irrigated vegetation in the UR category of the DWR Land Use Survey

Region	Percent of Irrigated Area
Fresno	11%
Kern	9%
Sacramento	5%
Tulare	16%

The results of the evaluation show that a relatively low percentage of the area is actually irrigated. This would indicate that the applied water and energy requirement would be less in terms of vegetative water use when compared to an irrigated crop. Household use was not examined.

One possible reason for the results of this evaluation is that the ranchette owners may not have a cost-effective source of irrigation water. Since it is unlikely that a crop grown by the owner would provide a significant source of income, it may not be cost-effective for the farmer to drill an irrigation well and pay for the electricity for pumping or to use treated city water. If untreated surface water were available, it would seem that the percent of irrigated area would be greater. The cost of water from an irrigation or water district is significantly less than the cost of treated water and may not have a capital cost as great as the cost of drilling a groundwater well.

The DWR Land Use Survey for Fresno County categorized <u>some</u> of the fields by water source. The results indicated that a relatively large percent of UR categorized areas had surface water available. However, the majority of the fields were either not classified or classified as unknown with regard to irrigation source. How the water source was classified is an important and unknown question. The DWR ground truths each of their surveys. If UR land was classified as supplied with surface water because of its proximity to an irrigation canal, it may be erroneous to assume that the land has the ability to obtain water from that canal. The results of this evaluation can be found in **Attachment E**.

Desalination

As California's water crisis has continued to escalate, interest in desalination has significantly increased. Recent developments in lower pressure membrane technology have especially piqued interest because of the lower operating cost associated with this technology (Glater, 2003). Historically, desalination plants have been used primarily for treating seawater. However, as the salinity level of fresh water sources has increased, desalination of brackish water (fresh water with a high salinity level) has begun to expand.

A number of desalination plants was constructed in the coastal regions of California during the 1987-1992 drought, the largest of which are located in Morro Bay and Santa Barbara. The desalination process at these plants requires 8.8 MWh/AF and 6.5 MWh/AF, respectively (Chaudhry, 2003). Currently, there are five proposed desalination projects located in Southern California that are expected to require less than 3.6 MWh/AF for the desalination process (Chaudhry, 2003). In comparison, it requires a net energy consumption of approximately 3.0 MWh/AF to send water from the Delta to Metropolitan Water district of Southern California (MWD), not including treatment (the estimate of 3.0 MWh/AF accounts for pumping and generation of the water along the State Water Project). This Delta water requires approximately 0.09 MWh/AF of energy for treatment to become potable (Chaudhry, Personal Communication). The figure below shows that with the rising energy costs, the cost of importing water into Southern California has increased. The cost of seawater desalination has decreased because of technological improvements. It is predicted that the cost of desalination will continue to decrease and by 2006 will be approximately the same as the 2002 cost of importing water (~$490/AF) (Chaudhry, 2003).

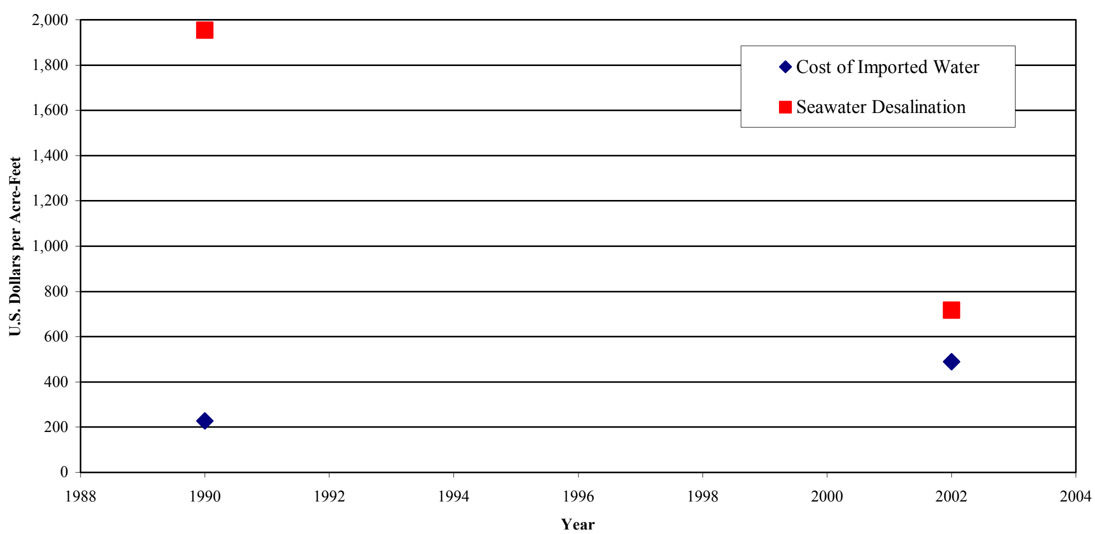


Figure 9. Approximated cost of importing water into MWD of SC compared to the cost of seawater desalination in 1990 and 2002. Adapted from a figure in Chaudhry, 2003.

The decreasing cost of desalination opens up the potential for use by the agricultural sector. Drainage water along the Westside of the Central Valley is very high in salts, specifically selenium. Restrictions on disposal of this drainage water have caused significant problems throughout this region. Some districts currently pick up the drainage water at the tail end of the district, pump it back to the head and mix it with incoming freshwater from the California Aqueduct. The salt is then spread over the entire district. The result of this practice is that the salinity levels in the irrigation water continue to increase, affecting the crop yields.

As the cost of desalination continues to decrease it may be economically feasible to remove the salts from this drainage water. With reverse osmosis, the amount of energy required is a function of the salinity of the irrigation water. Since drainage water has a salinity level significantly less than seawater, the amount of energy needed will be less (this is discussed further below). If it is cost effective to treat drainage water, it could potentially "free up" a significant amount of water for use elsewhere in the state. The amount of water that would need to be treated could be as much as 300,000 AF per year (270 MGD, if spread evenly throughout the year).

A study at Buena Vista Water Storage District in the late 1990's showed a cost to treat drainage water through reverse osmosis of $300 per AF, including capital expenditures for the plant itself and operation and maintenance costs. This cost did not include expenditures for facilities to capture drainage water, dispose of brine, or deliver treated water (Frankenberger et al., 1999). A detailed discussion of studies conducted, as well as types of technologies used for drainage water desalination, can be found in Frankenberger et al., 1999.

Brine Disposal

The desalination and disposal of the contaminated brine could have a significant impact on future energy requirements. There are four major brine disposal methods used throughout the world. These methods are:

- Return to the ocean
- Deep Well Injection
- Evaporation Ponds
- Solar Ponds

The first option (return the salt to the ocean) poses significant problems for inland-sited desalination plants. Unless the water (either the brine, influent, or drainage water) can be transported long distances, it is not an option. The NIBY (not in my back yard) sentiments in coastal communities are very strong.

Deep well injection has been used for many years throughout the world to dispose of hazardous and industrial waste (Glater, 2003). It generally involves injecting the waste into a confining layer around a mile deep. Another option is injecting effluent into oil wells that are no longer in use. Deep well injection can be an effective method of brine disposal; however, Glater (2003) pointed out a few limitations:

1. Availability of suitable well sites
2. Costs involved in conditioning the waste brine and injection
3. Possibility of contamination of fresh water strata if leakage occurs in the well casing through seismic activity or corrosion
4. Uncertainty of the well half-life, which can only be estimated using mathematical simulation techniques

Evaporation ponds are one of the most widely used techniques of inland desalination brine disposal. However, they are not suited for regions with significant rainfall and variable evaporation rates (Glater, 2003). Ponds must be large in order to have significant evaporation, and the capital cost associated with land purchase alone can be significant. Deep percolation must be prevented. All current evaporation ponds are generally double lined with polymer-based sheets to prevent groundwater contamination (Glater, 2003). This is a large component of the capital cost. An additional consideration is the environmental effects, especially with migrating waterfowl. Shallow open water bodies in inland areas of California are prime attractors for migrating birds. However, the drainage water is high in selenium, which is toxic to riparian species.

The use of salt-gradient solar ponds may be an effective way of treating and storing drainage water (Frankenberger et al., 1999). The salt-gradient solar pond has three zones of different salt concentrations, which act to keep the zones separate. The top and bottom zones are homogenous convective zones and the middle zone is non-convective and has its own salt gradient (Frankenberger et al., 1999). The depths of the ponds range from less than a meter to several meters. The figure below shows a typical schematic of a solar pond.

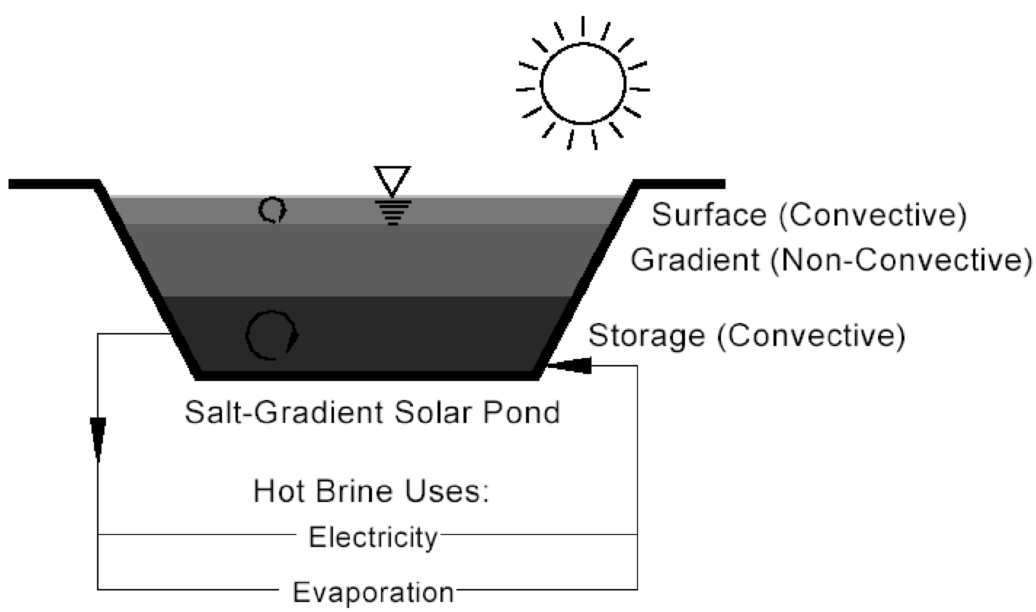


Figure 10. Salt-gradient solar pond. Figure provide by Frankenberger et al., 1999.

The bottom zone is heated through conduction. Solar radiation penetrates through the non-convective zone, heating the bottom zone. The heated water can be used to generate electricity to help operate the desalination plant. A study was conducted in Los Banos, CA from 1985 to 1989, where a Rankine-cycle engine was used for generation of electricity. The water temperatures in the bottom zone reached 180 degrees F (Frankenberger et al., 1999). However, the study was discontinued as a result of an EPA-ordered shutdown of all drainage water in the region, which fed the plant (Glater, 2003).

Further research would be needed in order to determine the feasibility of salt-gradient solar ponds as an integrated method of brine disposal and water treatment. The problem of final disposal of the salt still remains, of course.

Energy Requirement of Drain Water Desalination

There are a number of variables that will influence the future energy requirements regarding desalination of drainage water. If solar ponds are feasible, the amount of energy required for desalination from outside of the system may be significantly less than without these ponds. The energy requirement is a function of the salinity level of the influent, as well as the target level of the effluent. The current energy requirement for desalination of seawater, 3.6 MWh/AF, is higher than the requirement for drainage water; however, current data on the actual energy requirement is lacking. In a presentation made by Ron Enzweiler, from WaterTech Partners, to the CALFED Water Use Efficiency Subcommittee in 2002, the energy required for desalination of drainage water was estimated to be approximately 2.5 MWh/AF. If 300,000 AF of drainage water were treated per year, the annual gross energy required for treatment would be 750,000 MWh/Year.

RESERVOIR STORAGE SENSITIVITY TO CLIMATE CHANGE

Global warming is a major concern throughout the world. There have been continued debates on whether it is actually occurring, what the cause is, what the effect will be, and when the potential climate change will be felt. Climate change is predicted to occur because human activities are changing the chemical composition of the earth's atmosphere (USEPA, 1997). Analysis and debate regarding all the effects that this will have on California are beyond the scope of the report. However, there is one particular predicted event that can have a dramatic effect on water resources, in addition to energy generation and demand. That is earlier snowmelt and increased rainfall at upper elevations of the Sierra Nevadas.

Snow acts as a reservoir, delaying the release of water into the spring and early summer when the demand from urban and agricultural vegetation begins to increase. Throughout the Sierra Nevada range, dams have been constructed to create lakes and reservoirs that delay rainfall and snowmelt runoff until it is needed downstream. In effect, there are two reservoirs: snow and man-made reservoirs and lakes. In some cases, these work in conjunction to provide outflow just when it is needed. In other cases, reservoirs have been constructed with sufficient capacity to hold multiple years' worth of snowmelt and rainfall runoff without affecting outflow.

A number of reservoirs in the central to southern San Joaquin Valley do not have sufficient storage capacity to delay inflows more than 1-2 months. ITRC conducted an analysis to examine the effects of increased winter and spring rainfall and earlier snowmelt on reservoir storage and outflow. The analysis utilized predictions from the U.S. EPA (1997) and the Intergovernmental Committee on Climate Change (McCarthy, 2001) to conduct the analysis. These predictions include:

- Appreciable increases in precipitation are projected: 20-30% (with a range of 10-50%) in spring and fall, with somewhat larger increases in winter. Little change is projected for summer.
- More precipitation will occur as rain and less as snow.
- Snowmelt will occur earlier in the season.
- Winter runoff will increase, while spring and summer runoff will decrease.

The reservoir sensitivity analysis was conducted for eight reservoirs in the central to southern San Joaquin Valley. The table below shows data for each reservoir collected from the U.S. Army Corp of Engineers (USACOE) and the California Department of Water Resources (DWR). Minimum storage volumes for each reservoir were taken from data in the reservoir operations manual or from phone interviews with reservoir operations personnel. The usable storage was estimated from the maximum and minimum storage values.

Table 29. Reservoir information for 10 reservoirs used in the reservoir sensitivity analysis

All Values in Acre-Feet	Dam Name							
	Friant	Buchanan	Pine Flat	Terminus	Success	Isabella	New Melones	Don Pedro
Maximum Storage	520,500	150,000	1,000,000	143,000	82,300	568,000	2,400,000	2,030,000
Estimated Min Storage	130,000	10,092	100,000	4,066	5,000	80,000	300,000	1,250,000
Estimated Usable Storage	390,500	139,908	900,000	138,934	77,300	488,000	2,100,000	780,000
3 yr. Avg. Annual Inflow	1,228,711	44,376	1,243,824	313,868	90,393	424,282	741,524	2,203,540

The figure below shows the average annual inflow compared to the usable storage. Reservoirs that have more inflow than storage must release water much sooner than reservoirs with more capacity. Therefore, it is predicted that the reservoirs with a lower usable storage to annual inflow ratio will be more sensitive to climate change.

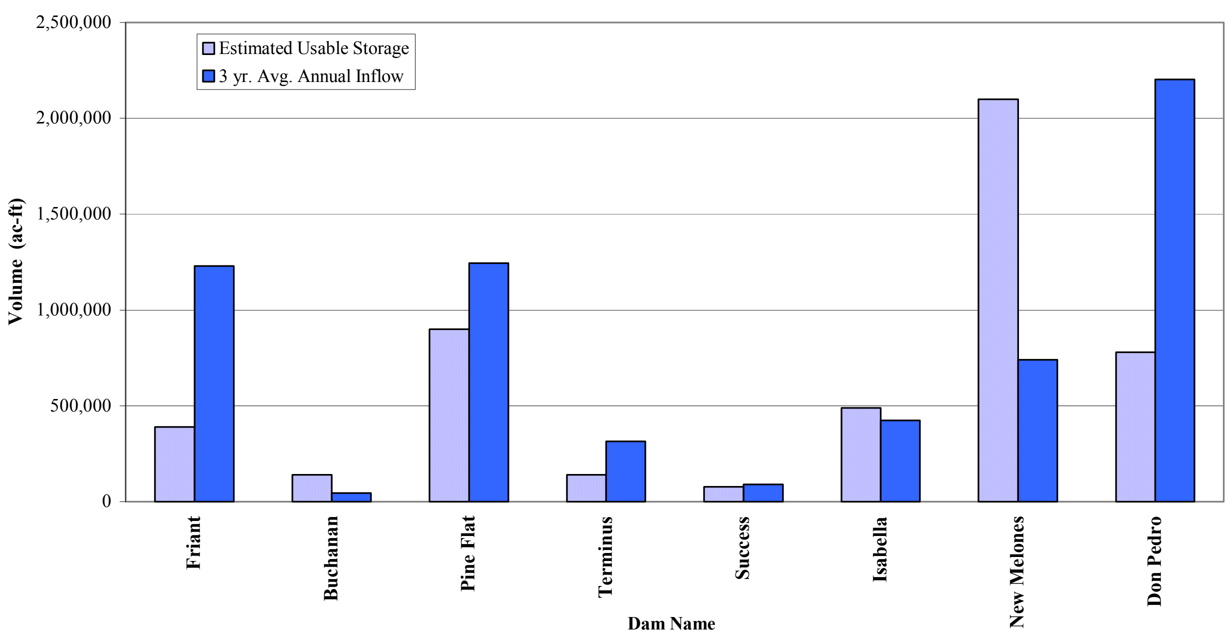


Figure 11. Average annual inflow compared to the estimated usable storage

The reservoir inflows were adjusted based on the predicted changes in rainfall and snowmelt patterns. The late winter and early spring inflows were increased and the late spring and summer inflows were decreased. However, these adjustments were made so that the annual inflow did <u>not</u> change significantly (same annual volume of runoff). The assumption made by ITRC is that while the timing of the inflows may change, the annual inflow volume will not be significantly impacted. The figure below shows how the inflow timing impacts the reservoir releases at Friant Dam near Fresno, California. The shaded area indicates the volume of water that is currently being released from the dam that will not be available if the predicted climate changes occur, with the assumption that reservoir releases will exceed current releases once the reservoir reaches maximum capacity and will be less than current releases once the reservoir reaches minimum capacity. When the storage is in between the maximum and minimum storage, the future outflow will equal the current outflow (i.e., reservoir operation will not change unless physical constraints force it to).

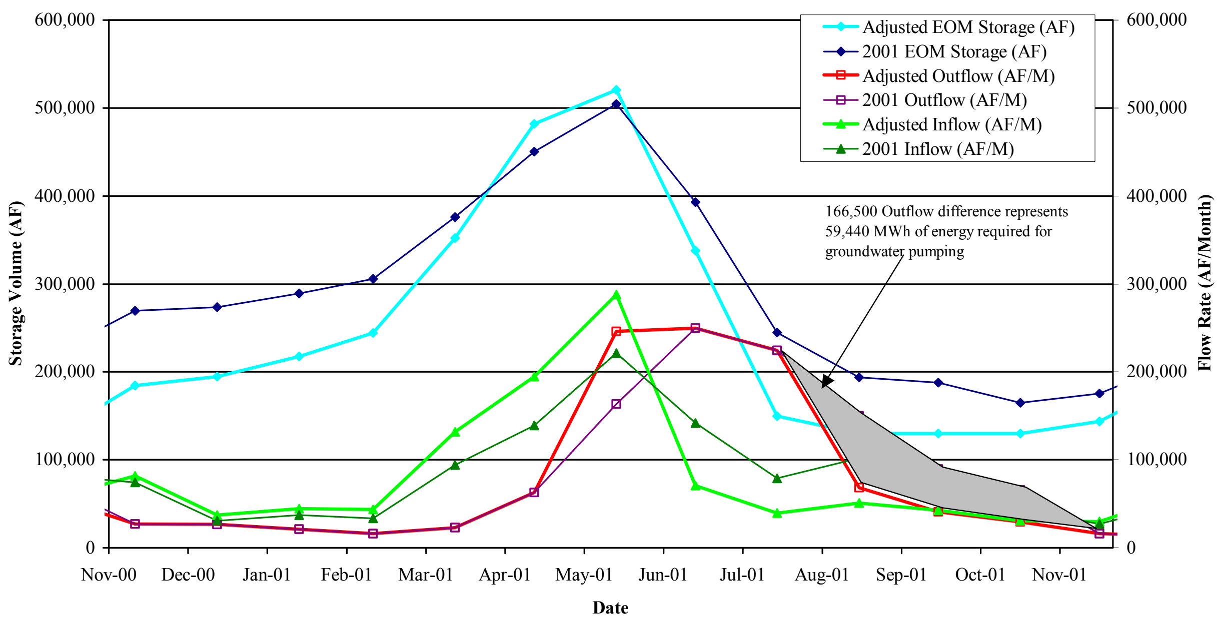


Figure 12. Reservoir sensitivity analysis of Friant Dam. The shaded area indicates the reduction in outflow during the peak summer months.

Currently, snowmelt slows the inflow into the reservoir so that water can be released throughout the peak irrigation season. The end of the month (EOM) storage closely emulates the seasonal inflow pattern. The maximum reservoir elevation occurs near the beginning of the summer and the 2001 outflow (releases) are then maximized to meet summer demands. The adjusted inflow indicates higher volumes of inflow in the spring until early summer, when the inflow drops dramatically. Since the reservoir storage is limiting, the dam operators would be forced to release water earlier than they would under current operation so that the capacity is not exceeded (May adjusted outflow is greater than May 2001 actual outflow). This water would then not be available for release during the late summer and fall (August-November).

Over the past 30 years it has become increasingly difficult to increase the amount of large-scale surface storage through construction of large dams. In some cases, existing dams can be raised slightly in order to provide more storage. However, even this can be difficult with current environmental and construction concerns, and the results are limited. What will most likely occur is an increase in groundwater storage programs in the affected areas.

Urban and agriculture will still have their highest demands during the summer months, so they will be forced to pump more groundwater when surface water becomes unavailable. This will have a significant impact on future energy requirements. ITRC estimated this energy requirement using the estimated on-farm groundwater pumping energy requirement calculated in the **On-Farm Groundwater Pumping** section of this report. It was assumed that the volume of surface water that would no longer be available would have to be pumped from the groundwater aquifer.

Using the current energy required to pump groundwater on-farm to estimate the amount of future energy that will be required also assumes that the overall pumping plant efficiency and the pumping water level will both be the same. However, with a significant increase in groundwater pumping in a region, groundwater levels will probably drop. To overcome groundwater overdraft, water that must be released from reservoirs so they do not exceed capacity will probably be distributed into recharge basins. This water would be allowed to percolate into the groundwater aquifer to help maintain the groundwater level.

Some of the reservoirs analyzed did not show any significant change in reservoir outflow (table below). This indicates that the reservoirs have sufficient capacity to hold the water until it is needed. Other reservoirs only showed outflows impacted for certain years and not others. The table below shows the results of the sensitivity analysis. Cells that are blank indicate no data was available to complete the analysis. Values of zero indicate that the outflow was not impacted.

Friant, Terminus, and Don Pedro Dams were significantly impacted by the climate change for each year analyzed. These dams also have significantly less storage than annual average inflow volume. The results assume no change in reservoir operation unless physical constraints warranted the change. If the operation were changed, the results would likely be different. The analysis also did not take into account the potential increase in evaporation from the reservoir surface or increased evapotranspiration demand by agriculture and urban vegetation as a result of climate change.

Table 30. Results of reservoir sensitivity to a significant climate change

	Dam Name															
	Friant		Buchanan		Pine Flat		Terminus		Success		Isabella		New Melones		Don Pedro	
Year	Reduced Summer Outflow (AF)	Resulting MWh increase	Reduced Summer Outflow (AF)	Resulting MWh increase	Reduced Summer Outflow (AF)	Resulting MWh increase	Reduced Summer Outflow (AF)	Resulting MWh increase	Reduced Summer Outflow (AF)	Resulting MWh increase	Reduced Summer Outflow (AF)	Resulting MWh increase	Reduced Summer Outflow (AF)	Resulting MWh increase	Reduced Summer Outflow (AF)	Resulting MWh increase
1996															256,110	93,224
1997															185,312	67,454
1998																
1999																
2000	235,889	84,212	0	0	0	0	32,950	13,510	0	0	0	0	0	0		
2001	166,536	59,453	0	0	0	0	16,291	6,679	1,262	459	0	0	0	0		
2002	150,689	53,796	0	0	86,365	36,273	22,262	9,127	0	0	25,438	15,543	0	0		
Average	**184,371**	**65,821**	**0**	**0**	**28,788**	**12,091**	**23,834**	**9,772**	**421**	**153**	**8,479**	**5,181**	**0**	**0**	**220,711**	**80,339**

Sum of Reservoir Averages	**466,605**	**173,357**

FUTURE RESEARCH

Future research topics were discussed in a Nov. 24, 2003 workshop held at the CEC offices in Sacramento. The major points and recommendations, plus additional ideas supplied by ITRC, are found in Attachment I at the end of this report.

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ATTACHMENT A
Irrigation District Pumping

ATTACHMENT A
IRRIGATION DISTRICT PUMPING

The cost of energy for pumping is one of the largest expenses that some districts incur. In parts of California, districts must pump every drop of water that they deliver to water users. In other parts, districts do not have to do any pumping; all of their water is fed through gravity. Some districts pump surface water out of canals or rivers into pipelines or open channels. In some cases, this is the only lift the water needs so that it can be delivered to the water users. In other cases, multiple pump stations are used to pump surface water throughout the district. Some districts pump groundwater to supplement the surface water supply. Many of these districts are called water storage districts. In years of surplus they recharge the groundwater and in years of deficit they use some of that stored water.

The amount of energy used by districts varies significantly throughout California. This attachment will explain the methodology and procedures used to estimate the amount of surface and groundwater pumping by irrigation districts on a regional basis throughout the state.

Studies conducted by the Irrigation Training and Research Center were used in this analysis. The studies include the *Benchmarking of Flexibility and Needs of California Water Districts for 1995*, *2000*, and *2002*, the *Evaporation from Irrigated Agriculture Land in California*, as well as other technical reports conducted throughout the state. District surveys and water management plans for eighty-seven districts throughout California were used to help estimate district pumping requirements. These sample districts had a combined irrigated acreage of approximately 4,350,000 out of a total estimated 9,126,200 irrigated acres in California.

Methodology

The goal of analyzing the *Benchmarking of Flexibility and Needs* survey data and the water management plans was to estimate: (a) the KWh/AF required to pump surface water and groundwater, and (b) find the volume of water supplied by the district to water users per acre (AF/acre).

The average annual water deliveries, district irrigated acreage, number of groundwater wells, average annual power cost to pump, and average cost per kilowatt-hour were the basis of the estimation of each district's energy requirement and volume of water supplied to farmers.

The estimated annual energy used for district surface water pumping was determined using different methods depending on what type of information was available. Generally, energy use by district groundwater pumping was determined first. The static groundwater level, typical regional drawdown, estimated column losses, discharge pressures, and average regional pump efficiencies were used to calculate the KWh/AF requirement. This data was obtained from a number of sources. Static groundwater level (SWL) was obtained from the surveys, the estimated column loss (CL) and drawdown (DD) were obtained from pump company interviews, discharge pressures (DP) were estimated by ITRC, and the average regional overall pumping plant efficiencies (OPPE) were obtained from the ITRC CEC Ag Peak Load Reduction Program Pump Test Database (see **Attachment C**). The total dynamic head (TDH) was calculated as:

TDH = SWL+DD+CL+DP

Each district was assigned an ETo zone based on its location in the state. The SWL varies by individual district, but the DD, CL, OPPE, and DP vary by ETo zone only because individual district data was not available. The KWh/AF groundwater pumping requirement was calculated using the following equation:

KWh/AF = (TDH/(OPPE%/100))*1.023

This equation can be formulated as:

KWh/AF = IHP*0.746/(GPM*(60/325,850))

IHP=WHP/OPPE=(GPM*TDH/(3960*OPPE))

KWh/AF = (GPM*TDH/(3960*OPPE))*0.746/(GPM*(60/325850))

KWh/AF = (TDH/OPPE) * 1.023

Where,
IHP = Input Horsepower
WHP = Water Horsepower
GPM = Flow rate in gallons per minute

The total average annual volume of groundwater pumped by each of the sample districts was obtained from district water management plans. If a water management plan was not available, districts were called and asked the value. The calculated energy requirement (KWh/AF) for district groundwater pumping was multiplied by the total volume of groundwater pumped by each district to obtain the district energy requirement for groundwater pumping.

Separately, the total energy used by each district (groundwater and surface water pumping) was estimated by dividing the average annual power cost by the average cost per kilowatt-hour. Subtracting the energy needed for groundwater pumping from the total energy used by the district gives the energy used for surface water pumping. If a district did not pump groundwater, the total pumping energy usage was assumed to be equal to the energy used for surface water pumping.

The annual energy used by each of the 87 districts for surface water pumping was divided by the annual surface water deliveries to obtain the energy required per volume of surface water pumped (KWh/AF). Utilizing GIS, each district was assigned to a DWR ETo zone based on the district's location in the state. The energy requirements (KWh/AF) for groundwater and surface water pumping were weighted based on district size and averaged for each ETo zone. Surface deliveries (AF/acre) were also weighted by district size and averaged for each ETo zone.

Table A-1. Average irrigation district pumping energy requirement and groundwater and surface water deliveries by modified ETo zones weighted by district irrigated acres (for an average precipitation year)

Modified ETo Zone	Average Irrigation District Groundwater Pumping Energy Requirement (KWh/AF)	Average Irrigation District Surface Pumping Energy Requirement (KWh/AF)	Average Irrigation District Groundwater Pumping (AF/Acre)	Average Irrigation District Surface Supply (AF/Acre)
1	0	0	0	0.00
3	0	0	0	0.00
4	0	0	0	0.00
6	0	0	0	0.00
8	201	34	0.01	3.31
9	0	0	0	0.00
10	0	0	0	0.00
12a	209	9	0.12	2.80
12b	209	9	0.12	2.80
14	145	16	0.01	3.76
15	394	123	0.23	1.93
16	205	52	0.03	1.91
18	0	0	0	6.72

In order to calculate the total energy requirement for district surface and groundwater pumping, ITRC utilized ETo zone irrigated acreage that was estimated for the *Evaporation from Irrigated Agriculture Land in California* (ITRC Report No. 02-001; see the table below). Multiplying the average groundwater pumped by the districts and the surface water supplied by the districts (AF/Acre) in each zone by the total irrigated acreage in each zone provided the acre-feet of water supplied (AF) by all districts in a zone. Knowing the AF and the KWh/AF required to pump, the total energy requirement was estimated (KWh or MWh).

Table A-2. Total irrigated acres by modified ETo zone in California

Zone	Surface Acres	Sprinkler Acres	Drip/Micro Acres	Combination Acres	**Total Irrigated Acres**
1	18,057	21,119	7,641	7,109	53,926
3	110,202	123,408	68,903	50,009	352,522
4	18,660	8,177	18,709	1,226	46,772
6	120,611	114,211	93,515	31,012	359,349
8	22,296	6,648	29,200	376	58,520
9	105,725	43,583	82,773	5,577	237,658
10	109,177	53,343	32,225	8,429	203,174
12a	578,263	150,072	319,024	32,357	1,079,715
12b	183,548	47,635	101,262	10,270	342,716
14	1,342,862	422,749	365,207	91,358	2,222,176
15	1,132,305	474,454	434,750	126,149	2,167,658
16	776,274	315,897	198,189	97,297	1,387,657
18	331,726	188,762	60,222	33,612	614,322
					9,126,165

Example of district groundwater and surface water pumping requirements for Zone 15

Given

Groundwater pumping energy requirement	=	394 KWh/AF
Surface water pumping energy requirement	=	123 KWh/AF
District groundwater pumped	=	0.23 AF/Acre
District surface water delivered	=	1.93 AF/Acre
Total irrigated acreage	=	2,167,658 Acres

Energy use in Zone 15 for district groundwater (GW) pumping

(1) 2,167,658 Acres * 0.23 AF/Acre

= 498,561 AF of GW pumped

(2) 498,561 AF * 394 KWh/AF

= **196,433,168 KWh***

or ~196,433 MWh

*This value is different than the value reported because the AF/Acre was rounded. The value from Table A-1 was rounded; the actual value was 0.23339… AF/Acre, which results in an energy use of 199,386 MWh.

Energy use in Zone 15 for district surface water (SW) pumping

(1) 2,167,658 Acres * 1.93 AF/Acre
= 4,183,580 AF of SW supplied

(2) 4,183,580 AF * 123 KWh/AF
= **514,580,332 KWh*** or
~514,580 MWh

*This value is different than the value reported because the AF/Acre value was rounded. The value from Table A-1 was rounded; the actual value was 1.92611… AF/Acre, which results in an energy use of 514,605 MWh.

ATTACHMENT B
On-Farm Pumping

ATTACHMENT B
ON-FARM PUMPING

The annual volume of on-farm groundwater pumping for a typical year was estimated based on crop irrigation water demands such as crop evapotranspiration, leaching requirements, and frost protection, as well as estimated distribution uniformity and the availability of surface irrigation water deliveries. Once the volume of applied water was estimated, on-farm pump efficiency and total dynamic head data was used to estimate the energy required to pump that water on a regional basis.

Crop Irrigation Water Demands

This is made up of three categories: crop evapotranspiration of irrigation water (ETirr), the water required to leach salts below the rootzone (LRw), and the water required by some crops in some regions for frost protection.

Crop Evapotranspiration of Irrigation Water (ETirr)

Crop evapotranspiration of irrigation water (ETirr) differs from total crop evapotranspiration (ETc) by the amount of precipitation water that the crop utilizes for evapotranspiration. This will vary by region, soil type, and year. Recently, ITRC conducted a study to estimate the amount of evaporation from irrigated agriculture land throughout California (Burt et al., 2002). For this study, approximately 40 crops, on four soil types, in 13 ETo zones, using three irrigation methods, for three different precipitation years were modeled using the FAO 56 dual crop coefficient method (Allen et al, 1998). The model was a Quick Basic program originally developed by Dr. Richard G. Allen from the University of Idaho and modified by ITRC. A complete discussion of the procedures and methodology used for modeling can be found in Burt et al, 2002. As a result of the modeling, an estimate of ETirr was developed for each crop in each ETo zone throughout California, for three precipitation years: Dry, Wet, and Typical.

For this report, only the typical year ETirr values were used to estimate the energy use for a normal year. ETirr values were weighted based on soil type acreage and averaged for each crop in each zone for the three irrigation methods (Burt et al., 2002). The leaching requirement water and frost protection requirement for a typical year were then added to the ETirr value.

Table B-1. Crop evapotranspiration of irrigation water (ETirr) plus water for leaching requirement and frost protection for surface irrigation during a typical year

	Zone 1	Zone 3	Zone 4	Zone 6	Zone 8	Zone 9	Zone 10	Zone 12	Zone 13	Zone 14	Zone 15	Zone 16	Zone 18
	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr
Crop	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre
Apple, Pear, Cherry, Plum and Prune	1.42	1.89	2.04	2.23	2.40	2.32	2.28	2.78	2.53	3.00	3.54	3.63	
Apple, Pear, Cherry etc w/cover crop	2.73	3.26	3.22	3.74	3.77	3.82	3.77	4.16	3.81	4.30	4.95	5.02	
Immature Apple, Pear, Cherry etc	0.84	0.89	1.04	1.11	1.32	1.23	1.57	1.81	1.65	1.85	2.05	2.12	
Peach, Nectarine and Apricots	1.69	2.04	2.11	2.21	2.54	2.29	2.29	3.02		2.88	3.42	3.35	5.17
Immature Peach, Nectarine and Apricots	0.84	0.85	0.96	1.07	1.27	1.16	1.39	1.79		1.87	2.02	2.27	
Almonds		1.96		2.13	2.50		2.19	2.90	2.31	3.02	3.26	3.48	
Almonds w/ cover crop		2.83		3.26	3.36		3.29	3.80	3.58	3.86	4.35	4.34	
Immature Almonds		0.91		1.02	1.37		1.62	2.27	1.69	2.28	2.72	2.86	
Walnuts		1.95	2.28	2.41	2.71	2.52	2.51	3.42	2.41	3.16	4.01	4.19	
Immature Walnuts		0.92	1.04	1.07	1.28	1.23	1.57	1.81	1.65	1.86	2.02	2.10	
Pistachio				2.13	2.16		2.29	2.71	2.51	2.57	3.01	3.28	
Pistachio w/ cover crop				0.00	3.53	0.00	3.47	3.85	3.51	3.97	4.47	4.59	
Immature Pistachio				0.98	1.38	0.00	1.57	1.82	1.64	1.87	2.05	2.09	
Misc. Deciduous	1.76	1.97	2.04	2.28	2.42	2.49	2.13	2.79	2.02	3.01	3.52	3.55	5.30
Immature Misc. Deciduous	0.85	0.86	0.97	1.15	1.29	1.17	1.40	1.80	1.51	1.87	2.06	2.29	
Grain and Grain Hay	1.08	1.12	1.11	1.37	1.06	1.35	1.24	1.17	1.02	1.27	1.43	1.44	1.86
Rice							2.38	2.81		2.94	3.32		
Cotton				1.54			1.34	1.96		2.26	2.45	2.48	3.60
Safflower and Sunflower		1.28		1.55	1.25	1.46	1.47	1.54		1.58	2.15	2.44	2.47
Corn and Grain Sorghum	1.19	1.51	1.50	1.59	1.82	1.70	1.80	1.87	2.10	1.94	2.41	2.21	2.92
Beans		1.58	1.59	1.64	1.68	1.70	1.46	1.75		1.75	2.01	2.18	2.33
Misc. field crops	1.16	1.47		1.51	1.57	1.62	1.36	1.65		1.76	1.84	1.97	1.93
Alfalfa Hay and Clover	2.59	2.80	2.84	3.23	3.05	3.30	3.24	3.52	3.26	3.52	4.05	4.08	6.07
Pasture and Misc. Grasses	2.47	2.75	2.78	3.26	3.07	3.36	3.06	3.39	3.38	3.50	3.93	4.06	4.24
Small Vegetables (Double Crop)	1.87	1.92	1.86	2.16	2.01	2.14	0.90	1.40	0.85	1.40	1.62	1.60	1.92
Tomatoes and Peppers	1.46	1.73	1.77	1.98	1.97	1.98	1.16	1.35		1.31	1.82	1.92	2.62
Potatoes, Sugar beets, Turnip etc.	1.76	2.06		2.35	2.27	2.60	2.35	2.58		2.53	3.03	3.22	3.70
Melons, Squash, and Cucumbers	1.27	1.30	1.25	1.56	1.49	1.43	0.76	1.00		1.07	1.14	1.17	2.39
Onions and Garlic	1.36	1.30	1.28	1.61	1.32	1.54	1.34	1.40		1.29	1.51	1.53	2.86
Strawberries	1.28	1.57	1.59	1.64	1.69	1.71	1.46	1.78	1.53	1.75	2.06		
Flowers, Nursery and Christmas Tree	1.77	1.95	2.00	2.28	2.36	2.46	2.09	2.74	2.13	3.00	3.48	3.36	5.04
Citrus (no ground cover)	1.75	2.09	2.13	2.40	2.75	2.42	2.73	2.74		3.03	3.47	3.62	5.07
Immature Citrus	0.87	0.86	0.88	1.12	1.33	1.19	1.58	1.60		1.84	2.01	2.18	2.41
Avocado	1.78	1.85	2.06	2.17	0.00	2.52	2.15	2.44		0.00			
Misc Subtropical	1.78	2.14	2.17	2.44	2.83	2.47	2.78	2.82	2.66	3.02	3.57	3.71	5.33
Grape Vines			0.59			0.85	1.52	1.91	1.87	1.83	2.14	2.42	5.28
Grape Vines w/ cover crop			1.19			1.42	2.48	2.80	2.54	2.81	3.43	3.38	
Immature Grape Vines			0.55			0.74	1.23	1.41	1.33	1.42	1.68	1.77	2.49
Idle	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B-2. Crop evapotranspiration of irrigation water (ETirr) plus water for leaching requirement and frost protection for sprinkler irrigation during a typical year

	Zone 1	Zone 3	Zone 4	Zone 6	Zone 8	Zone 9	Zone 10	Zone 12	Zone 13	Zone 14	Zone 15	Zone 16	Zone 18
	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr
Crop	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre
Apple, Pear, Cherry, Plum and Prune	1.41	1.89	2.04	2.24	2.12	2.32	2.76	2.78	2.53	2.75	3.54	3.28	
Apple, Pear, Cherry etc w/cover crop	2.73	3.25	3.23	3.76	3.50	3.82	3.85	4.17	3.82	4.02	4.96	5.20	
Immature Apple, Pear, Cherry etc	1.02	1.18	1.35	1.11	1.63	1.57	1.60	1.86	1.86	1.85	2.12	2.30	
Peach, Nectarine and Apricots	1.69	2.04	2.11	2.21	2.22	2.32	2.55	3.01		3.01	3.43	3.11	5.06
Immature Peach, Nectarine and Apricots	0.98	1.05	1.19	1.07	1.50	1.39	1.63	1.99		1.99	2.26	2.06	
Almonds		1.82		2.13	2.16		2.74	2.90	2.31	2.57	3.26	3.06	
Almonds w/ cover crop		2.84		3.26	3.24		3.41	3.80	3.57	3.43	4.35	4.57	
Immature Almonds		1.25		1.03	1.73		2.04	2.41	1.87	2.38	2.86	2.34	
Walnuts		1.82	2.13	2.41	2.47	2.55	2.84	3.42	2.41	3.18	4.01	3.22	
Immature Walnuts		1.23	1.35	1.07	1.65	1.57	1.60	1.86	1.86	1.86	2.14	2.30	
Pistachio				2.13	2.16	0.00	2.29	2.72	2.51	2.57	3.01	3.27	
Pistachio w/ cover crop				0.00	3.45	3.57	3.49	3.87	3.51	3.98	4.50	4.89	
Immature Pistachio				0.97	1.61	1.57	1.60	1.85	1.85	1.87	2.11	2.30	
Misc. Deciduous	1.77	1.96	2.04	2.28	1.98	2.48	2.38	2.80	2.43	2.73	3.52	2.74	4.87
Immature Misc. Deciduous	0.99	1.07	1.20	1.15	1.51	1.40	1.64	2.00	1.70	1.98	2.29	2.08	0.00
Grain and Grain Hay	1.08	1.11	1.11	1.37	0.88	1.36	1.24	1.17	1.02	1.27	1.43	1.44	1.86
Rice													
Cotton				1.53			1.71	2.20		2.16	2.57	2.48	3.67
Safflower and Sunflower		1.28		1.55	1.24	1.45	1.48	1.54		1.58	2.15	2.45	2.47
Corn and Grain Sorghum	1.19	1.51	1.50	1.58	1.80	1.69	1.49	1.88	2.08	1.72	2.25	2.63	2.91
Beans		1.59	1.58	1.64	1.62	1.67	1.46	1.77		1.57	2.05	2.08	2.32
Misc. field crops	1.17	1.48		1.51	1.51	1.49	1.36	1.66		1.56	1.87	1.87	1.92
Alfalfa Hay and Clover	2.75	3.12	3.06	3.23	3.05	3.46	3.25	3.52	3.26	3.52	4.05	4.08	6.07
Pasture and Misc. Grasses	2.47	2.76	2.78	3.26	3.05	3.35	3.06	3.39	3.38	3.50	3.93	4.05	4.24
Small Vegetables (Double Crop)	1.77	1.83	1.78	2.33	0.82	2.29	1.56	1.54	0.87	1.51	1.77	1.03	2.06
Tomatoes and Peppers	1.46	1.73	1.77	1.98	1.13	1.97	1.19	1.35		1.43	1.80	1.92	2.62
Potatoes, Sugar beets, Turnip etc.	1.77	2.05		2.36	2.23	2.60	2.35	2.58		2.53	3.03	3.22	3.70
Melons, Squash, and Cucumbers	1.24	1.30	1.27	1.44	0.79	1.45	0.75	1.01		1.03	1.18	1.16	2.38
Onions and Garlic	1.35	1.30	1.28	1.61	1.01	1.54	1.34	1.40		1.29	1.51	1.53	2.86
Strawberries				1.64									
Flowers, Nursery and Christmas Tree	1.78	1.95	2.00	2.28	1.93	2.46	2.34	2.75	2.31	2.73	3.48	2.75	4.96
Citrus (no ground cover)	2.15	2.37	2.53	3.27	3.53	3.70	3.58	4.23		4.31	4.83	4.80	
Immature Citrus	1.16	1.16	1.23	1.90	2.55	2.23	2.52	3.07		3.19	3.38	3.50	
Avocado	2.88	2.86	2.92	2.95	0.78	3.30	4.23	4.02		3.12			
Misc Subtropical	2.20	2.43	2.58	3.28	3.62	3.76	3.64	4.25	2.80	4.32	4.94	4.88	
Grape Vines			0.59			2.27	1.64	1.91	1.87	1.83	2.14	2.43	
Grape Vines w/ cover crop			1.18			3.23	2.64	2.80	2.54	2.72	3.43	3.41	
Immature Grape Vines			0.72			1.95	1.77	1.39	1.39	1.42	1.68	1.82	

Table B-3. Crop evapotranspiration of irrigation water (ETirr) plus water for leaching requirement and frost protection for drip/microspray irrigation during a typical year

	Zone 1	Zone 3	Zone 4	Zone 6	Zone 8	Zone 9	Zone 10	Zone 12	Zone 13	Zone 14	Zone 15	Zone 16	Zone 18
	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr	ETirr
Crop	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre	AF/Acre
Apple, Pear, Cherry, Plum and Prune	1.58	1.92	1.97	2.00	2.43	2.36	2.49	2.98	2.97	3.08	3.33	3.70	
Apple, Pear, Cherry etc w/cover crop	2.34	2.86	2.82	3.26	3.23	3.33	3.48	4.30	4.02	4.38	4.96	5.02	
Immature Apple, Pear, Cherry etc	0.92	1.10	1.18	1.27	1.49	1.41	1.56	1.59	1.63	1.64	1.81	1.99	
Peach, Nectarine and Apricots	1.57	1.76	1.94	2.00	2.22	2.08	2.46	2.95		2.92	3.28	3.26	5.00
Immature Peach, Nectarine and Apricots	0.79	0.95	1.03	1.05	1.26	1.14	1.39	1.71		1.72	1.98	2.09	
Almonds		2.04		2.34	2.72		2.35	3.07	2.72	3.09	3.68	3.64	
Almonds w/ cover crop		3.00		3.27	3.72		3.15	4.09	3.49	3.88	4.51	4.57	
Immature Almonds		1.10		1.28	1.54		1.43	1.92	1.70	1.88	2.28	2.29	
Walnuts		1.93	2.14	2.03	2.22	2.44	2.12	3.16	2.94	3.39	3.70	3.85	
Immature Walnuts		1.11	1.18	1.28	1.49	1.41	1.56	1.59	1.63	1.64	1.81	1.98	
Pistachio				2.21	2.50	2.35	2.48	2.71	2.58	2.75	2.93	2.91	
Pistachio w/ cover crop				3.11	3.42	3.38	3.46	3.73	3.46	3.87	4.17	4.16	
Immature Pistachio				1.26	1.48		1.56	1.59	1.64	1.64	1.81	2.02	
Misc. Deciduous	1.42	1.62	1.77	1.84	2.05	2.05	2.67	2.97	2.83	2.95	3.31	3.34	5.16
Immature Misc. Deciduous	0.80	0.96	1.04	1.09	1.28	1.15	1.40	1.73	1.62	1.71	2.00	2.11	
Grain and Grain Hay													
Rice													
Cotton											2.42	2.52	
Safflower and Sunflower													
Corn and Grain Sorghum													
Beans		1.35	1.33	1.37	1.58	1.45	1.50	1.80		1.68	2.15	2.17	2.42
Misc. field crops	1.05	1.26		1.27	1.47	1.36	1.39	1.68		1.69	1.94	1.95	1.98
Alfalfa Hay and Clover													
Pasture and Misc. Grasses													
Small Vegetables (Double Crop)	1.52	1.60	1.48	1.79	1.74	1.62	0.91	1.24	1.22	1.32	1.49	1.49	2.10
Tomatoes and Peppers	0.99	1.07	1.11	1.24	1.23	1.19	1.23	1.42		1.42	1.81	1.81	2.67
Potatoes, Sugar beets, Turnip etc.	1.95	2.15		2.38	2.22	2.18	2.21	2.55		2.39	2.96	3.00	3.50
Melons, Squash, and Cucumbers	0.48	0.68	0.74	0.69	0.83	0.85	0.65	0.89		0.90	0.95	0.98	2.53
Onions and Garlic	1.26	1.18	1.13	1.31	1.23	1.28	1.30	1.35		1.26	1.56	1.58	2.62
Strawberries	1.15	1.35	1.33	1.37	1.61	1.45	1.50	1.82	1.67	1.68	2.15		
Flowers, Nursery and Christmas Tree	1.39	1.59	1.74	1.80	1.99	2.01	2.63	2.92	2.74	2.95	3.22	3.24	4.90
Citrus (no ground cover)	1.86	2.13	2.14	2.58	2.81	2.59	2.82	2.95		3.00	3.58	3.59	5.01
Immature Citrus	0.91	0.99	1.07	1.38	1.64	1.43	1.77	1.86		2.00	2.15	2.29	3.10
Avocado	1.60	1.61	1.79	2.33	2.54	2.23	2.67	3.04		2.23			
Misc Subtropical	1.90	2.18	2.18	2.61	2.87	2.64	2.87	2.96	2.48	3.00	3.68	3.67	5.28
Grape Vines		0.50	0.66	0.98	0.83	0.86	1.99	1.99	1.81	2.03	2.21	2.42	3.20
Grape Vines w/ cover crop		0.95	1.09	1.44	1.43	1.55	2.66	2.88	2.70	2.74	3.29	3.23	
Immature Grape Vines		0.82	0.68	1.11	1.43	0.97	1.39	1.27	1.21	1.25	1.39	1.53	1.60
Idle													

Leaching Requirement Water (LRw)

Leaching salts from the rootzone is an important component of the crop water requirement throughout most of California. The leaching requirement (LR) is calculated based on the crop salinity threshold (threshold ECe), the electrical conductivity of the irrigation water (ECw), and the crop evapotranspiration of irrigation water (ETirr). The general equation for LR as a fraction of ETirr is:

$$\mathbf{LR_f = ECw/[(5 \times ECe)-ECw]}$$

To combine ETirr and the LRw

$$\mathbf{ETirr+LRw = ETirr/(1-LR_f)}$$

The threshold ECe for each crop is given in the table below. The threshold ECe is the ECe at which the crop yield begins to decline. Crops that are more tolerant to soil salinity have a higher ECe than crops that have a lower tolerance.

Table B-4. Threshold ECe values used to calculate the leaching requirement

Crop	ECe, dS/m	Crop	ECe, dS/m
Apple, Pear, Cherry, Plum and Prune	1.5	Corn and Grain Sorghum	1.8
Apple, Pear, Cherry etc w/cover crop	1.5	Beans	1
Immature Apple, Pear, Cherry etc	1.5	Misc. field crops	3
Peach, Nectarine and Apricots	1.7	Alfalfa Hay and Clover	2
Immature Peach, Nectarine and Apricots	1.7	Pasture and Misc. Grasses	6
Almonds	1.5	Small Vegetables (Double Crop)	1.3
Almonds w/ cover crop	1.5	Tomatoes and Peppers	2.5
Immature Almonds	1.5	Potatoes, Sugar beets, Turnip etc.	1.7
Walnuts	1.5	Melons, Squash, and Cucumbers	2.5
Immature Walnuts	1.5	Onions and Garlic	1.2
Pistachio	1.5	Strawberries	1
Pistachio w/ cover crop	1.5	Flowers, Nursery and Christmas Tree	2
Immature Pistachio	1.5	Citrus (no ground cover)	1.7
Misc. Deciduous	1.5	Immature Citrus	1.7
Immature Misc. Deciduous	1.5	Avocado	1.3
Grain and Grain Hay	6	Misc Subtropical	1.3
Rice	3	Grape Vines	1.5
Cotton	7.7	Grape Vines w/ cover crop	1.5
Safflower and Sunflower	6	Immature Grape Vines	1.5

**Values were taken from Table 3-2 of the BRAE 331 text by Dr. C. Burt, BioResource and Agricultural Engr. Dept., Cal Poly, San Luis Obispo, CA*

The salinity of the irrigation water (ECw) varies throughout the state depending on the origin of the water. Colorado River water has a greater salinity content (higher ECw) than most other sources in California. Shallow groundwater along the Westside of the Central Valley also has a very high level of salinity but is rarely used as a primary source of irrigation water. In some cases, drain water is mixed with surface water, which increases the salinity level of the irrigation water. A brief analysis was conducted for the *Benchmarking of Flexibility and Needs 2002 Survey* of unpublished data regarding salinity levels in irrigation water. This data was not published because only a few districts knew the salinity of their irrigation water. California DWR water quality data was also examined to determine average ECw values. The table below shows the ECw values used for the modified ETo zones in California.

Table B-5. Estimated salinity of irrigation water throughout California

Zones	ECw dS/m
1,3,6,8,9,10,12a,12b,14	0.5
15,16	0.7
18	1.2

Frost Protection

Water is commonly used for frost protection on frost sensitive crops such as citrus, avocados, and grapes. It is most commonly used with microspray and sprinkler irrigation. Water is generally applied to the plant and soil surfaces, or to the soil exclusively, beginning a few hours before the predicted frost. As the water cools and begins to freeze, energy is released by the water as heat, which helps to protect the crop.

Frost protection using sprinklers and microspray irrigation is common in coastal regions, Napa and Sonoma Valleys, and along the eastside of the Central Valley where citrus is grown. The following table provides the information that was used to estimate the frost protection requirement for specific crops in specific zones throughout California.

Table B-6. Assumed information used to estimate typical year frost protection requirements

		Flow Rate		Number of Events per Year
		Microspray	Sprinkler	
Zones	Crop	GPM/Acre	GPM/Acre	
1,3,6,8,9	Vines, Citrus, Avocado	11	53	7
12	Citrus	11	53	10

The information in the table above was estimated from Snyder (2000), Nemani et al. (1999), and Jorgensen et al. (1996). An explanation of frost protection in California can be found in the *Principles of Frost Protection* (Snyder, 2000). The number of events per year and the actual flow rate of the irrigation system will vary. The values presented in the table above are ballpark estimates utilizing existing information. It was assumed that the irrigation system would operate for 12 hours per event.

Crop Irrigation Water Demand by Zone

Once all of the crop irrigation water demands were summed for each crop, irrigation type, and zone, an average zone evapotranspiration value was calculated. The crop irrigation water demand (ETirr+LRw+FP) was weighted based on acreage and averaged for the entire zone for each irrigation type.

In order to estimate the total applied water, a distribution uniformity factor had to be taken into account. The distribution uniformity for each region and irrigation type was determined utilizing ITRC experience with hundreds of irrigation system evaluations conducted by the ITRC Mobile Lab service.

Table B-7. Distribution uniformity estimate for three categories of irrigation methods throughout California

Surface	Sprinkler	Drip/Micro
0.70	0.75	0.80

An additional factor was included in the estimation of the volume of groundwater pumping. This factor accounts for the unavailability of surface water when farmers need it at specific times of the year. For example, in the Fresno area (Zone 12b) surface water is typically only available until mid-July. After the surface water ceases, farmers must pump groundwater to meet evapotranspiration demands. The calculations used in this study assume that the volume of water delivered by irrigation districts is limited only by volume, not by whether or not the district has surface water to deliver. The additional factor takes this timing aspect into account. This factor will be called the "Timing Factor" (TF). The Timing Factor values are shown by region in the table below. Additional explanation of this factor can be found in the main body of this report.

Table B-8. Timing Factor used to account for groundwater pumping due to surface water not being available at certain times of the year

Mod. ETo Zone	Timing Factor
1,3,4,6,8,9,10,12a,15,16,18	0.9
12b	0.65
14	0.85

The total volume of on-farm groundwater pumped during a typical year is estimated using the following equation:

On-Farm GW Pumping = [(ETirr+LRw+FP)/DU] – (District Deliveries*TF)

Table B-9. Total estimated on-farm groundwater pumping in California by modified ETo zone

DWR ETo Zone	On-Farm Groundwater Pumping AF/Year
1	123,965
3	824,486
4	138,046
6	959,939
8	56,387
9	880,841
10	669,478
12a	972,963
12b	559,014
14	425,118
15	3,880,110
16	2,533,649
18	61,432
Total	**12,085,400**

The energy requirement per volume pumped on-farm (KWh/AF) was estimated based on static groundwater water level, average drawdown, column loss, discharge pressure, and pump efficiency in each zone (see the table below). The average drawdown and column loss information was the same as used for district groundwater pumping and was obtained through pump company interviews conducted by ITRC. The average pump efficiency was obtained from the CEC Agricultural Peak Load Reduction Program On-Farm Pump Testing Database. More information on on-farm overall pumping plant efficiency can be found in **Attachment D**. The total dynamic head (TDH) is calculated based on the static water level, drawdown, column loss, and a discharge pressure. Average static water level values for each zone were obtained from DWR groundwater data and contour maps.

Putting all of the pieces together, the total volume of groundwater pumped for each irrigation method was calculated based on the volume of water per acre requirement and the irrigation type acreage in each zone. Multiplying the total volume of groundwater pumped by the energy required to pump it (KWh/AF), the total energy use by on-farm groundwater pumping was estimated for each zone. The KWh/AF groundwater pumping requirement was calculated using the following equation:

$$\mathbf{KWh/AF = (TDH/(OPPE\%/100))*1.023}$$

An explanation of how this equation was developed can be found in **Attachment A**.

Table B-10. On-farm pumping plant data used to calculate the on-farm energy requirement for pumping groundwater

Zone	Pump Depth	Drawdown (ft)	Discharge Pres (ft)	Column Loss (ft)	TDH	Ave. Pumping Efficiency	On Farm GW KWh/AF
1	180	35	9	8	233	48.3	493
3	180	35	9	8	233	48.3	493
4	180	35	9	8	233	48.3	493
6	180	35	9	8	233	54.0	441
8	65	35	9	4	113	40.3	287
9	150	35	9	7	201	56.9	362
10	200	35	9	9	253	50.8	510
12	160	15	9	2	186	52.3	364
13	164	15	9	2	190	54.5	357
14	138	50	9	5	202	52.7	392
15	263	35	9	3	310	51.9	611
16	216	20	9	3	248	53.2	478
18	100	20	9	5	134	53.2	257

A significant portion of on-farm electric pump motors have been replaced with diesel engines. Pump company representatives were interviewed to help quantify the percentage of electric versus non-electric motors used for on-farm pumping throughout the state. Estimates for each zone, as well as a statewide estimate, are shown in the table below.

The total energy, as well as only the electric energy required for on-farm groundwater pumping, is also shown in the table below. On-farm groundwater pumping makes up the majority of energy use for agriculture water in the State. The bulk of this energy is used along the Westside and in the southern portion of the Central Valley.

Table B-11. Estimated total electric energy requirement for on-farm groundwater (GW) pumping

Zone	On-Farm GW energy requirement KWh/AF	On-Farm GW Pumping Total AF	On-Farm GW Pumping Total Energy KWh	Percent Electric Pumps On-Farm	Percent non-electric Pumps On-Farm	On-Farm GW Pumping Electric KWh
1	493	123,965	61,070,924	90	10	54,963,832
3	493	824,486	406,180,149	90	10	365,562,134
4	493	138,046	68,007,880	90	10	61,207,092
6	441	959,939	422,992,256	95	5	401,842,643
8	287	56,387	16,192,669	90	10	14,573,402
9	362	880,841	318,999,334	80	20	255,199,467
10	510	669,478	341,596,776	80	20	273,277,421
12a	364	972,963	354,225,775	80	20	283,380,620
12b	357	559,014	199,546,739	80	20	159,637,391
14	392	425,118	166,759,703	65	35	108,393,807
15	611	3,880,110	2,371,148,439	70	30	1,659,803,907
16	478	2,533,649	1,209,911,735	70	30	846,938,215
18	257	61,432	15,818,166	90	10	14,236,349
California Total		**12,085,428**	**5,952,450,545**	**82**	**18**	**4,499,016,280**

On-farm Booster Pumping

Booster pumps are used by farmers throughout California to increase the pressure of surface and groundwater for sprinkler and drip/micro irrigation (as well as some surface irrigation systems). These pumps can utilize a significant amount of energy throughout the irrigation season. The pump efficiency and the discharge pressure required to operate the irrigation system were used to estimate the energy requirement.

On the Westside of the San Joaquin Valley (ETo Zones 15 and 16), surface irrigation methods using tailwater and gated pipe require booster pumps. A discharge pressure estimate of 3 psi was used to calculate this energy requirement.

Sprinkler irrigation systems used on row crops typically require a discharge pressure of approximately 70 psi, and undertree sprinklers require a booster pump discharge pressure of approximately 50 psi. Years of experience designing and evaluating sprinkler irrigation systems by ITRC personnel were used to obtain this estimate. The discharge pressures used for this analysis are shown in the table below by region. They differ by region based on the crop in each region typically utilizing sprinkler irrigation systems. Coastal regions use sprinklers mainly for row crops. On the Westside of the Central Valley, sprinklers are used for both tree and row crops. However, on the Eastside of the Central Valley, the majority of sprinkler systems are undertree.

Table B-12. Estimated booster pump discharge pressures by region for sprinkler irrigation

Zone	Sprinkler Booster Pump Discharge Pres. PSI
1	70.0
3	70.0
4	70.0
6	70.0
8	50.0
9	70.0
10	60.0
12a	50.0
12b	50.0
14	55.0
15	60.0
16	60.0
18	60.0

Drip and microspray irrigation system evaluations conducted throughout the state by ITRC and other agencies (private and regional resource conservation districts) were used to obtain the typical booster pump discharge pressures. These values were averaged on a regional basis and applied to the appropriate modified ETo zones. Pump efficiencies were assumed to be the same as the modified ETo zone average on-farm groundwater overall pumping plant efficiency from the On-farm Pump Testing Database (**Attachment D**).

Table B-13. Average discharge pressure of booster pumps used for drip/microspray irrigation throughout California

DWR ETo Zone	Drip/Micro Booster Pump Discharge Pres. PSI
1	44
3	55
4	44
6	44
8	45
9	50
10	45
12	38
13	34
14	45
15	42
16	40
18	48

Using the discharge pressure and average pump efficiency, the energy requirement per volume of water pumped was calculated (KWh/AF). The following equation was used to estimate the energy requirement based on the OPPE and discharge pressure (~TDH):

$$KWh/AF = (TDH/(OPPE\%/100))*1.023$$

An explanation of how this equation was developed can be found in **Attachment A**.

The total applied volumes of water for sprinkler irrigation and drip/micro throughout the state, and surface water in Zones 15 and 16, were multiplied by the KWh/AF requirement to obtain energy usage.

Table B-14. Average booster pump energy requirement throughout the State

Zone	On Farm Drip/Micro Booster Pump Energy Requirement KWh/AF	On Farm Surface Booster Pump Energy Requirement KWh/AF	On-Farm Sprinkler Booster Pump Energy Requirement KWh/AF	On-Farm Combination Booster Pump Energy Requirement KWh/AF
1	215	0	342	171
3	269	0	342	171
4	215	0	342	171
6	193	0	306	153
8	264	0	293	147
9	208	0	291	145
10	209	0	279	140
12a	172	0	226	113
12b	147	0	217	108
14	202	0	247	123
15	191	14	273	143
16	178	13	267	140
18	213	0	267	133

Table B-15. Total and electric energy required to operate booster pumps in California. Values are rounded.

Zone	On Farm Drip/Micro BP Total Energy KWh	On Farm Surface BP Total Energy KWh	On-Farm Sprinkler BP Total Energy KWh	On-Farm Combination BP Total Energy KWh	Total Energy Usage by Booster Pumps, KWh	Percent Electric Pumps	Percent Non-Electric Pumps	Total electric energy usage by Booster Pumps, KWh
1	3,339,000	0	17,359,000	2,471,000	23,169,000	90	10	20,852,000
3	38,566,000	0	104,817,000	17,812,000	161,196,000	90	10	145,076,000
4	10,391,000	0	9,213,000	542,000	20,146,000	90	10	18,132,000
6	36,373,000	0	109,858,000	9,595,000	155,825,000	95	5	148,034,000
8	16,768,000	0	6,834,000	120,000	23,722,000	90	10	21,350,000
9	54,315,000	0	52,582,000	2,562,000	109,459,000	80	20	87,567,000
10	21,182,000	0	48,537,000	3,694,000	73,412,000	80	20	58,730,000
12a	226,326,000	0	133,984,000	15,102,000	375,412,000	80	20	300,329,000
12b	72,580,000	0	48,350,000	5,413,000	126,343,000	80	20	101,075,000
14	300,954,000	0	404,936,000	46,007,000	751,897,000	65	35	488,733,000
15	330,855,000	60,468,000	519,704,000	72,002,000	983,029,000	70	30	688,121,000
16	135,378,000	38,735,000	316,937,000	52,338,000	543,387,000	70	30	380,371,000
18	87,581,000	0	343,147,000	30,551,000	461,280,000	90	10	415,152,000
California Total	**1,334,608,000**	**99,203,000**	**2,116,258,000**	**258,209,000**	**3,808,277,000**			**2,873,522,000**

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ATTACHMENT C
Irrigation District Pump Efficiency

ATTACHMENT C
IRRIGATION DISTRICT PUMP EFFICIENCY

In June of 2001, the Irrigation Training and Research Center was contracted by the California Energy Commission to be a grant administrator for the SB5X Agricultural Peak Load Reduction Program (APLRP) for agricultural water agencies throughout California. This program contained three categories of projects, the second of which offered rebates for pump testing and pump retrofit/repair. Data from each pump test submitted to ITRC for rebate was organized in a database. As of September 2003, 1027 water district pump tests had been submitted to ITRC for rebate.

Data in this attachment focuses on the irrigation district overall pumping plant efficiency data that has been collected by ITRC through the APLRP. A total of 962 pump tests were used for this analysis. This is less than the total number of tests submitted because some of the tests were rejected or the pumping plant efficiencies could not be calculated because the pump tester was unable to determine the total dynamic head.

Overall Pumping Plant Efficiency as a Function of Motor Input Kilowatts

The pump tests submitted to ITRC were conducted on pumps that had motor input kilowatt (kW) values ranging from 2.4 - 1,620 kW. The majority of pumps tested had input kW values ranging from 2.4 – 100 kW. However, as expected with irrigation districts, a significant number of tests were conducted on pumps with more than 100 kW of motor load.

Since the motor input kW relates to motor size and has a major impact on energy use, it is generally predicted that the higher the input kW, the better the overall pumping plant efficiency will be. Pumps that cost more to operate are thought to be better maintained to keep the operating cost as low as possible. On average this prediction is true. However, some smaller pumps had relatively good efficiencies (greater than 65%) and some larger pumps had lower efficiencies. The figures below show the results of this analysis. In order to reduce outliers from single pumps tested in some ranges of input kW, the figures showing averages trends combined pumps with greater than 400 kW motor load.

A trend analysis was conducted in the first two figures. The first figure containing all of the data points has a relatively low r^2 value (0.28), indicating a relatively low correlation between input kW and OPPE. However, when the OPPE is averaged over a range of input kW values, as in the second figure, a logarithmic trend analysis indicates a good correlation in the data (r^2=0.99).

The third figure is a bar chart showing the average OPPE in specific ranges of input kW. The number of tests averaged in each range is indicated at the top of each bar.

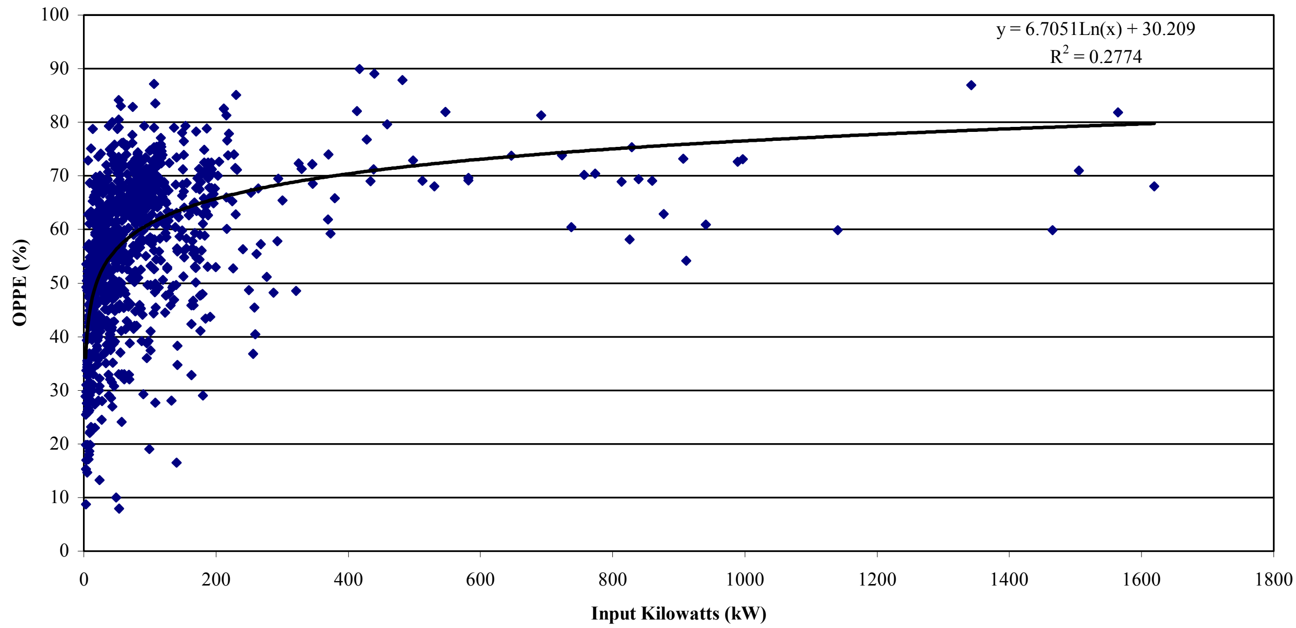


Figure C-1. Pump efficiency as a function of motor input kW for each pump tested

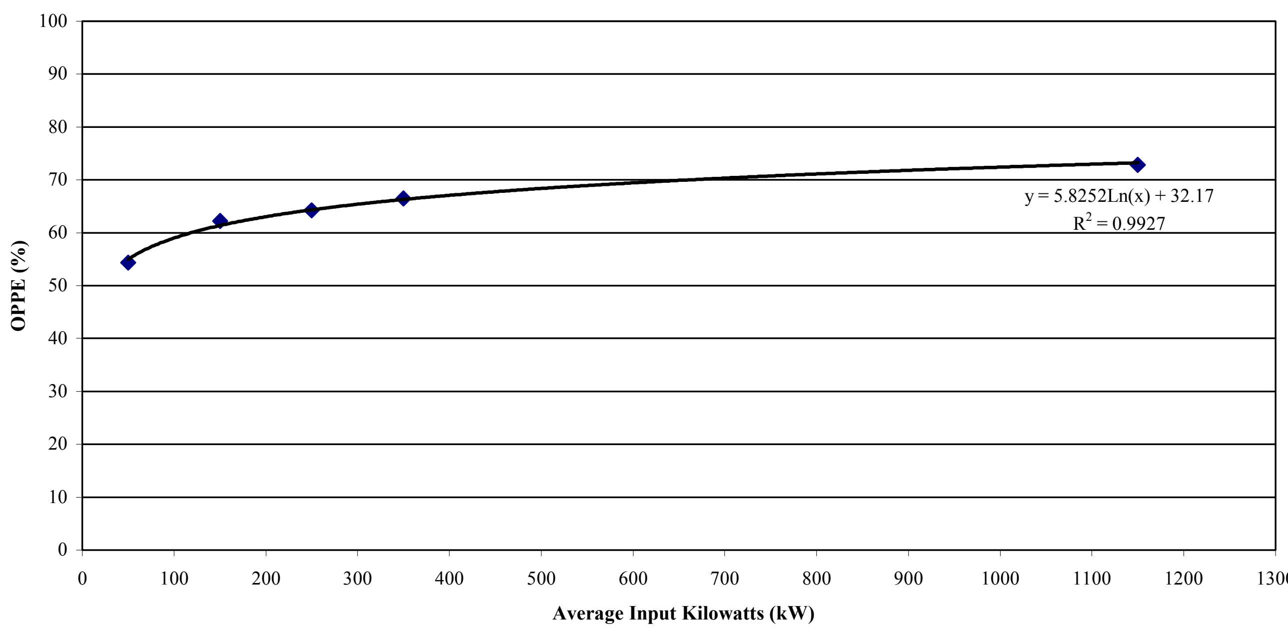


Figure C-2. Average overall pump efficiency as a function of average motor input kW

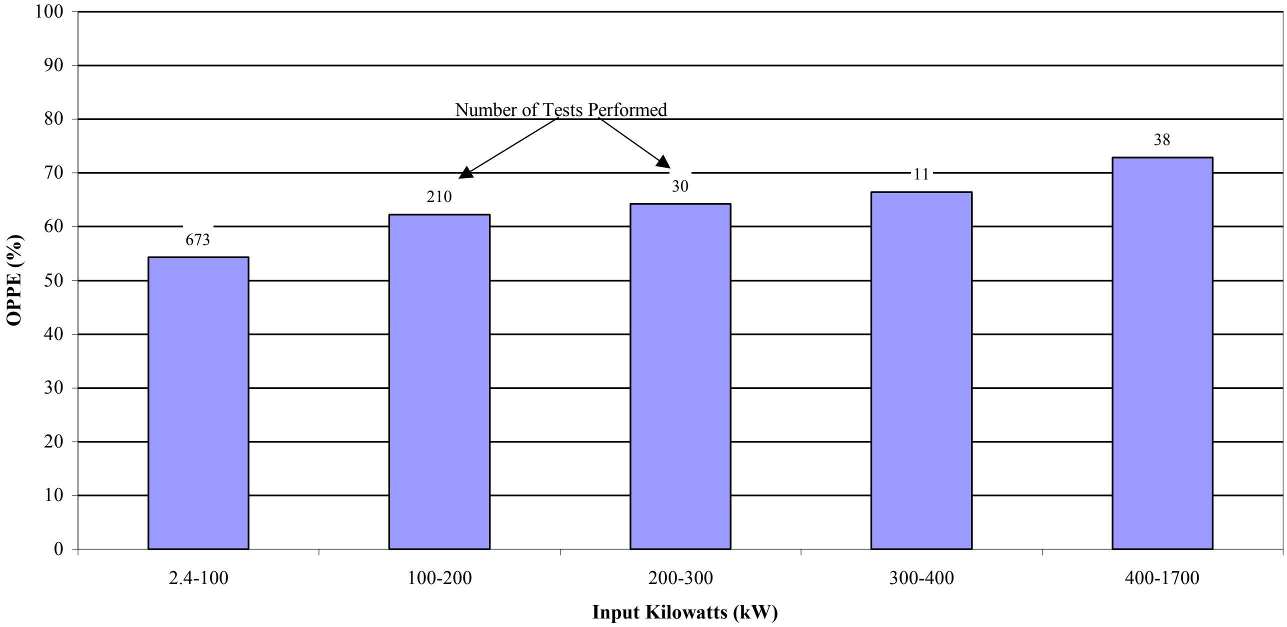


Figure C-3. Average overall pumping plant efficiency and the number of tests performed in each kW range

Overall Pumping Plant Efficiency as a Function of Location in California

Irrigation district pump tests were conducted through the CEC APLRP throughout California. The majority of irrigation districts are located in the San Joaquin and Sacramento Valleys or in the desert regions. Most district pumping occurs in the valleys. District pumping in the desert regions is generally limited to tailwater and drain water pumping.

For this analysis, California was split into zones based on a modified DWR ETo Zone Map. These zones coincide with the zones used throughout this report. The table below lists the average district pump efficiency throughout the state.

Table C-1. Average irrigation district pump efficiency by zone

Zone	Average Irrigation District OPPE (%)	Number of Tests Conducted
8	34	22
12a&b	57	159
14	50	158
15	59	409
16	58	155
18	47	78

Zones 12a, 12b, 15, and 16 had the highest average overall pumping plant efficiency. These zones are located in the San Joaquin Valley. This region also has most district pumping and district energy use.

Overall Pumping Plant Efficiency as a Function of Total Dynamic Head

An important component of overall pumping plant efficiency is total dynamic head (TDH). THD is the total head the pump imparts on the water. The TDH is the sum of the discharge pressure, drawdown, static water level, and column losses.

The following figures indicate the OPPE as a function of TDH. Most of the pumps tested had relatively low TDH, which indicates that these pumps are most likely used for canal and pipeline lifts (as opposed to deep well pumps). The higher the TDH, the more energy is required to pump the same volume of water. Therefore, in theory, pumps with higher TDH should have higher OPPE. However, pumps operating at less than 200 feet of head had both high and low efficiencies. Pumps operating between 100 and 200 feet of head had the highest average efficiency. And pumps operating above 200 feet had significantly lower efficiencies. The figures below show the OPPE for each pump tested and the average OPPE over a range of efficiencies.

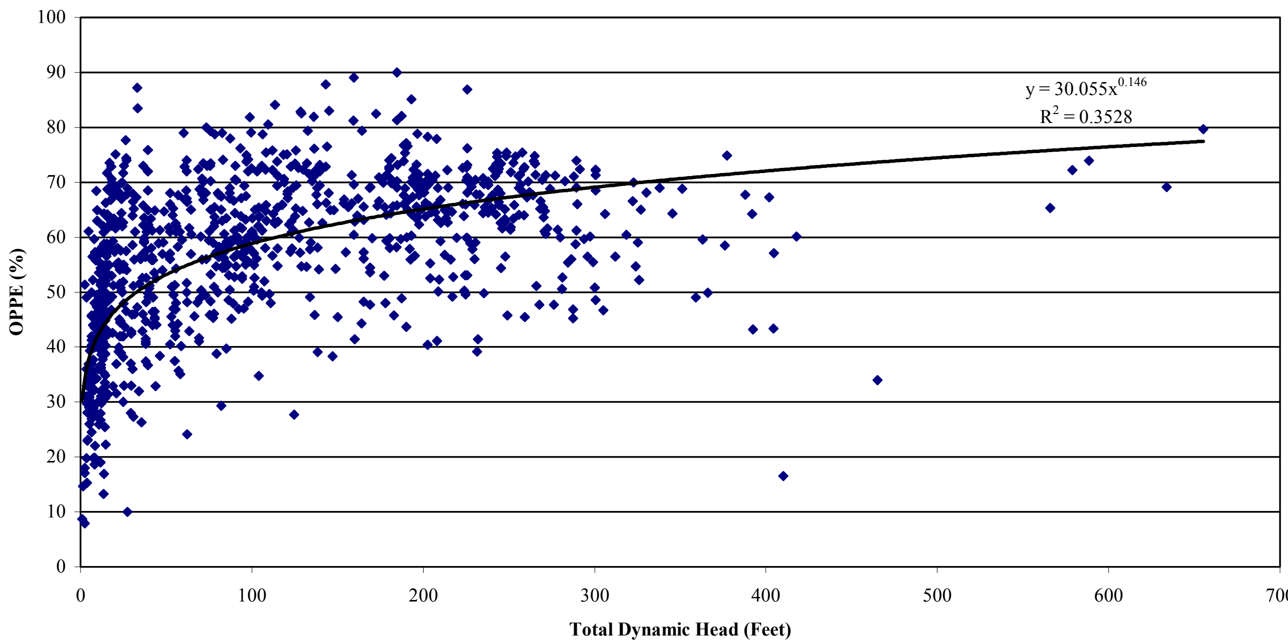


Figure C-4. Pump efficiency as a function of motor input kW for each pump tested

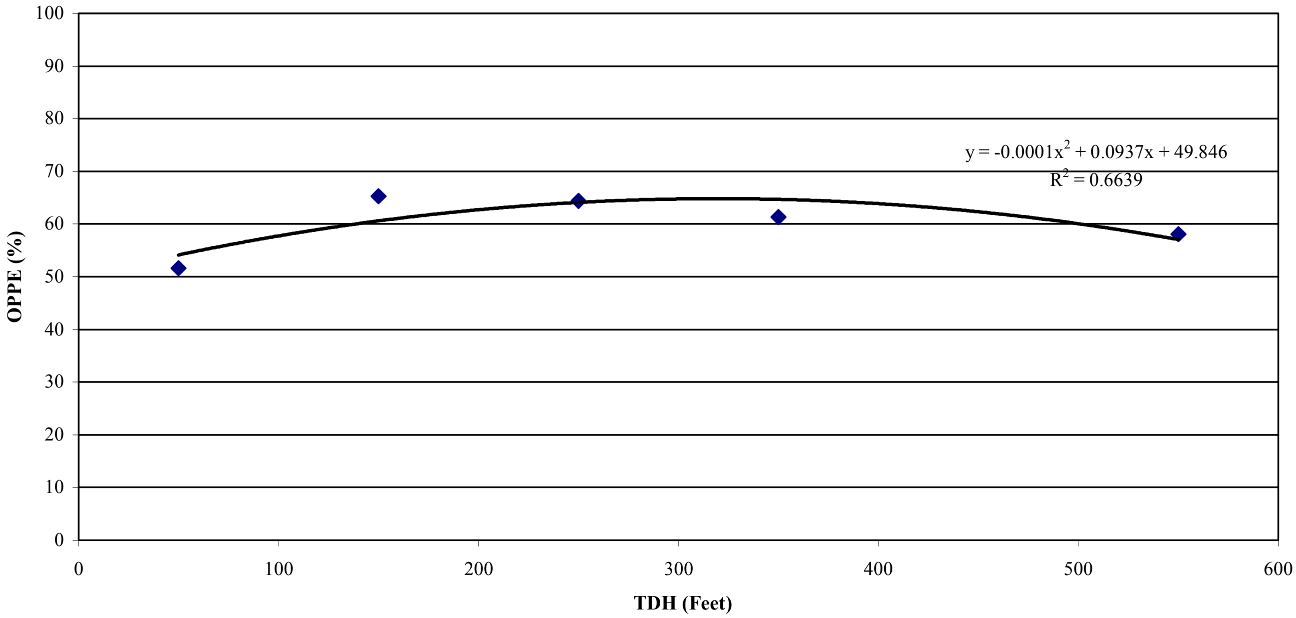


Figure C-5. Average overall pump efficiency as a function of average TDH

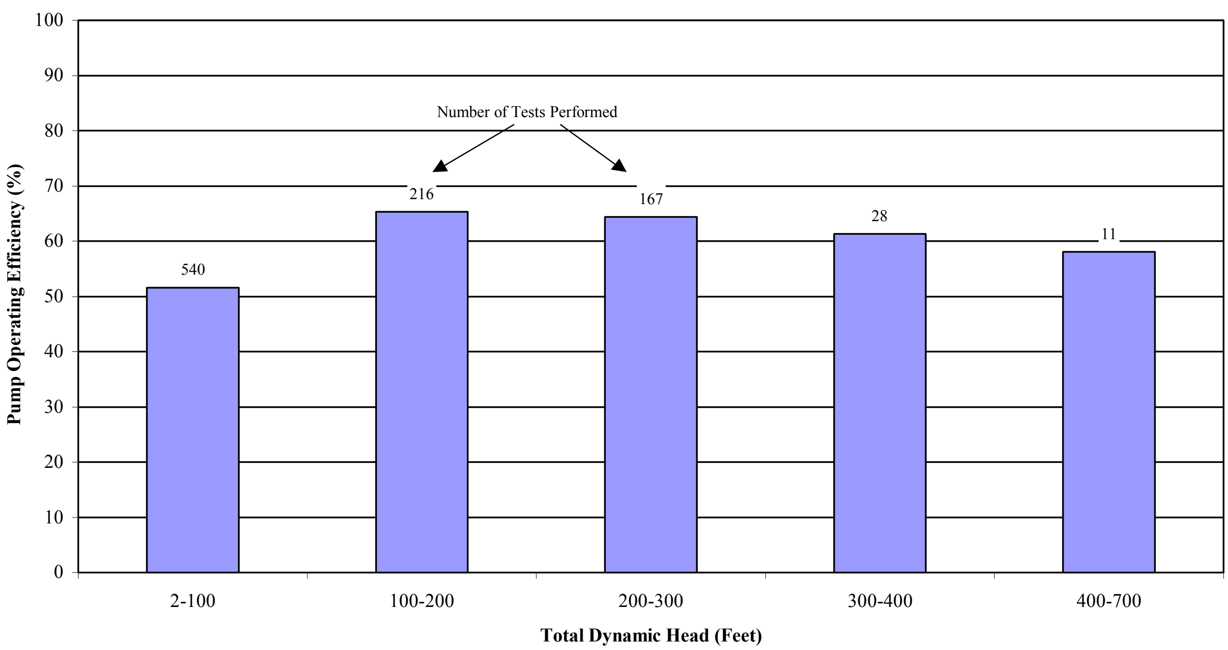


Figure C-6. Average overall pumping plant efficiency by TDH and the number of tests performed in each TDH range

ATTACHMENT D
On-Farm Pump Efficiency

ATTACHMENT D
ON-FARM PUMP EFFICIENCY

In June of 2001, the Center for Irrigation Technology (CIT) at California State University Fresno was contracted by the California Energy Commission to be a grant administrator for the SB5X Agricultural Peak Load Reduction Program (APLRP) for individual farms throughout California. This program contained three categories of projects, the second of which offered rebates for pump testing and pump retrofit/repair for individual farmers. Data from each pump test submitted to CIT for rebate was organized in a database. The data used for this analysis was provided by CIT to ITRC.

Data in this attachment focuses on the overall pumping plant efficiency data that has been collected by CIT through the APLRP. A total of 2893 pump tests were used for this analysis.

Overall Pumping Plant Efficiency as a Function of Motor Input Kilowatts

The pump tests submitted to CIT were conducted on pumps that had motor input kilowatt (kW) values ranging from 0.78 - 149 kW.

The figures below show the relationship between on-farm overall pumping plant efficiency (OPPE) and input kilowatts (kW). Overall, there is no visible relationship between input kW and OPPE. Looking at the average OPPE over a range of input kW; the values show moderate increase in OPPE as the input kW increases. However, this is variable, probably because of the relatively small range of input kW for all pump tests.

A trend analysis was conducted in the second figure. This trend has a relatively low r^2 value (0.47), indicating a relatively low correlation between input kW and OPPE. Because of the lower pump efficiencies near the upper range of input kW, extrapolating this polynomial equation to pumps at higher input kW will give false values. In all likelihood, pumps at higher input kW will have higher operating efficiencies.

The third figure is a bar chart showing the average OPPE in specific ranges of input kW. The number of tests averaged in each range is indicated at the top of each bar.

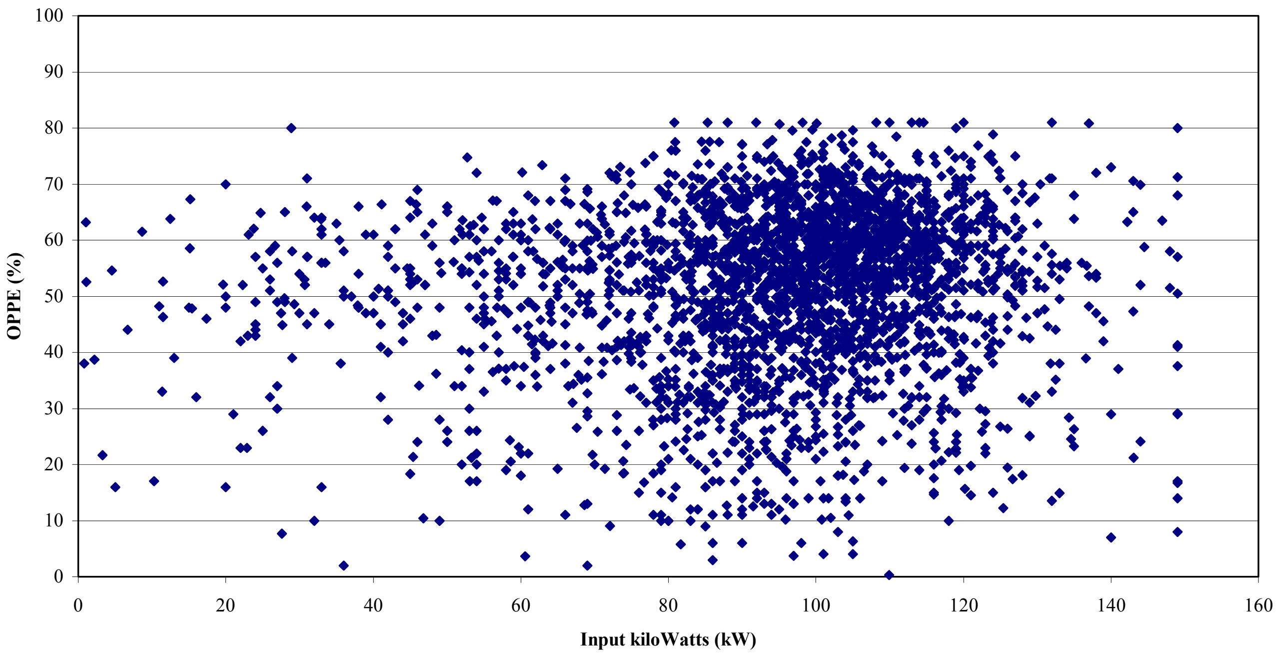


Figure D-1. On-farm pump efficiency as a function of motor input kW for each pump tested

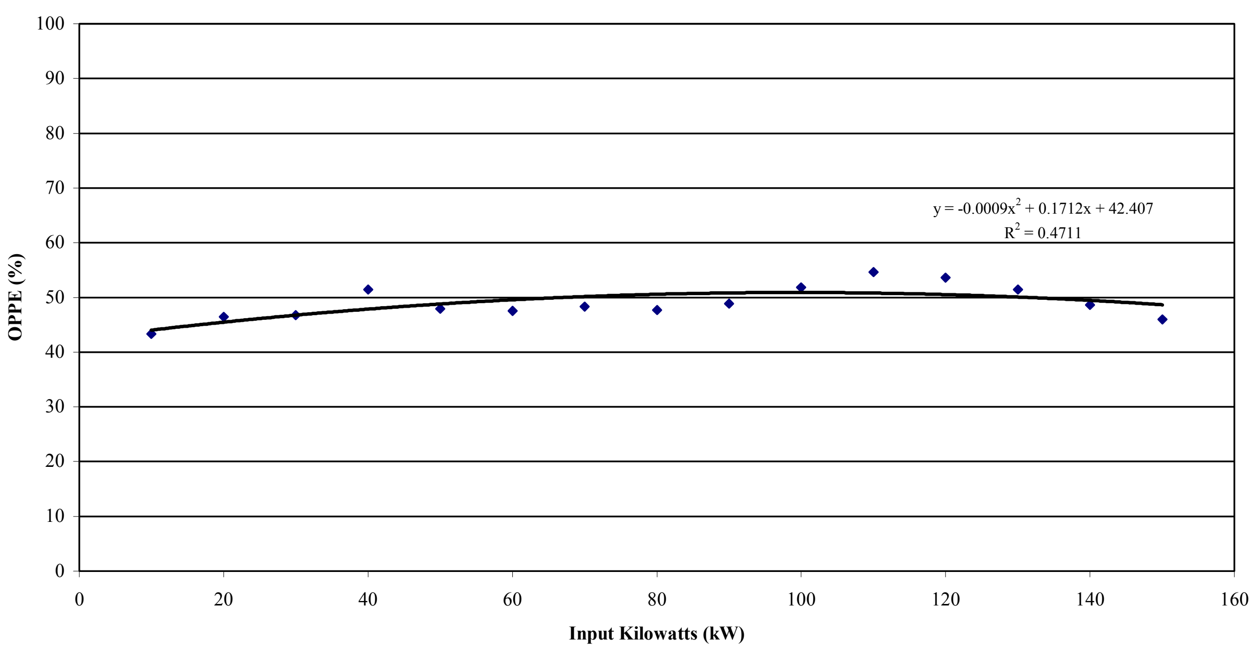


Figure D-2. Average on-farm overall pump efficiency as a function of average motor input kW

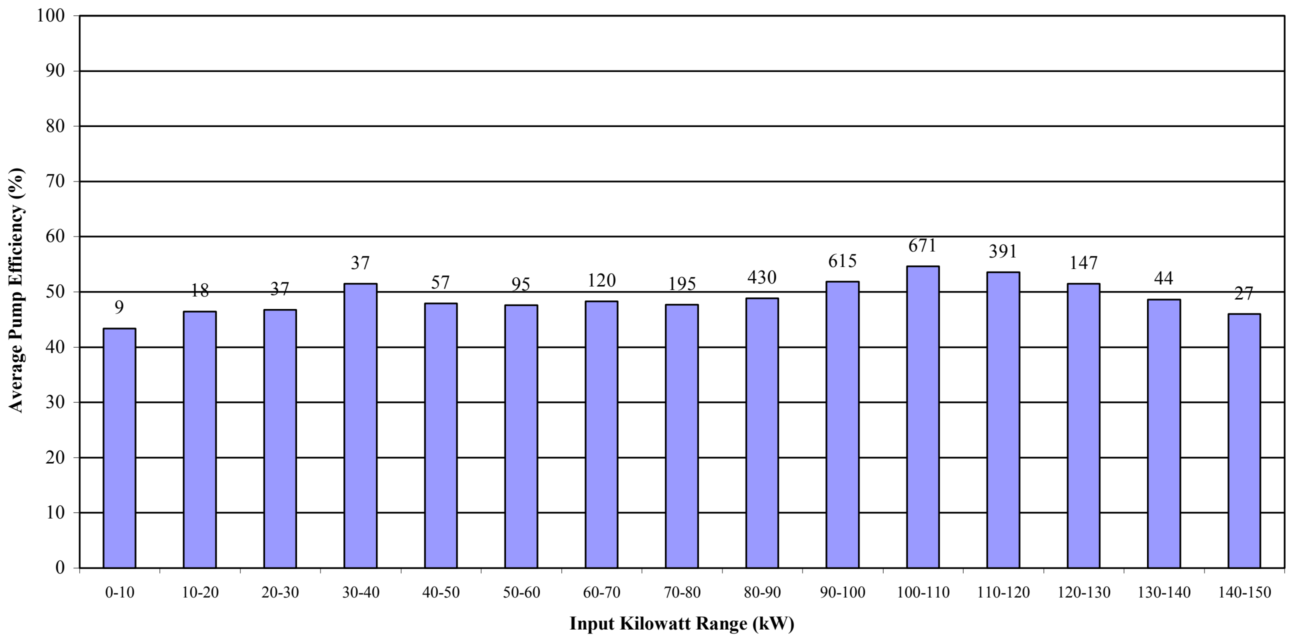


Figure D-3. Average on-farm overall pumping plant efficiency and the number of tests performed in each kW range.

Overall Pumping Plant Efficiency as a Function of Location in California

On-farm pump tests submitted for rebate through the APLRP were conducted throughout California. The majority of the pumps tested were along the eastern side of the San Joaquin Valley. A significant number of tests was also conducted in the coastal region and in Salinas Valley.

For this analysis, California was split into zones based on a modified DWR ETo Zone Map. These zones coincide with the zones used throughout this report. The table below lists the average on-farm pump efficiency throughout the state.

Table D-1. Average on-farm overall pumping plant efficiency by zone

Zone	Average On-Farm OPPE (%)	Number of Tests Conducted
3	48.3	321
6	54.0	342
8	40.3	307
9	56.9	37
10	50.8	14
12a	52.3	790
12b	54.5	677
14	52.7	236
15	51.9	33
16	53.2	37
18	53.2	99

The average OPPE did not vary significantly throughout the state, except for Zone 8 (Solano and Napa Counties). Otherwise, the average OPPE was in the lower 50% range over most of California.

Overall Pumping Plant Efficiency as a Function of Total Dynamic Head

An important component of overall pumping plant efficiency is total dynamic head (TDH). THD is the total head the pump imparts on the water. The TDH is the sum of the discharge pressure, drawdown, static water level, and column losses.

The following figures indicate the OPPE as a function of TDH for on-farm pumps. Most of the pumps tested have a TDH between 0.4 and 200 feet. Some of the lower pump TDH values are probably booster pumps used for surface irrigation. However, on-farm booster pumps can have high TDH values because sprinkler and drip/microspray irrigation systems require significant operating pressure.

The first figure shows the OPPE for each pump in this analysis. Because of the variation in the OPPE and the number of pumps tested over the complete range of TDH values, no significant trend is visible. Pumps have a wide range of OPPE at the lower TDH ranges.

By analyzing the average OPPE over a range of TDH values an obvious trend emerges (second figure below). As the TDH increases, the average OPPE increases. However, at the upper range of TDH (500-1100 feet, average TDH of 800 feet) the value decreased. This may be due to the low number of pumps tested in this range, skewing the average.

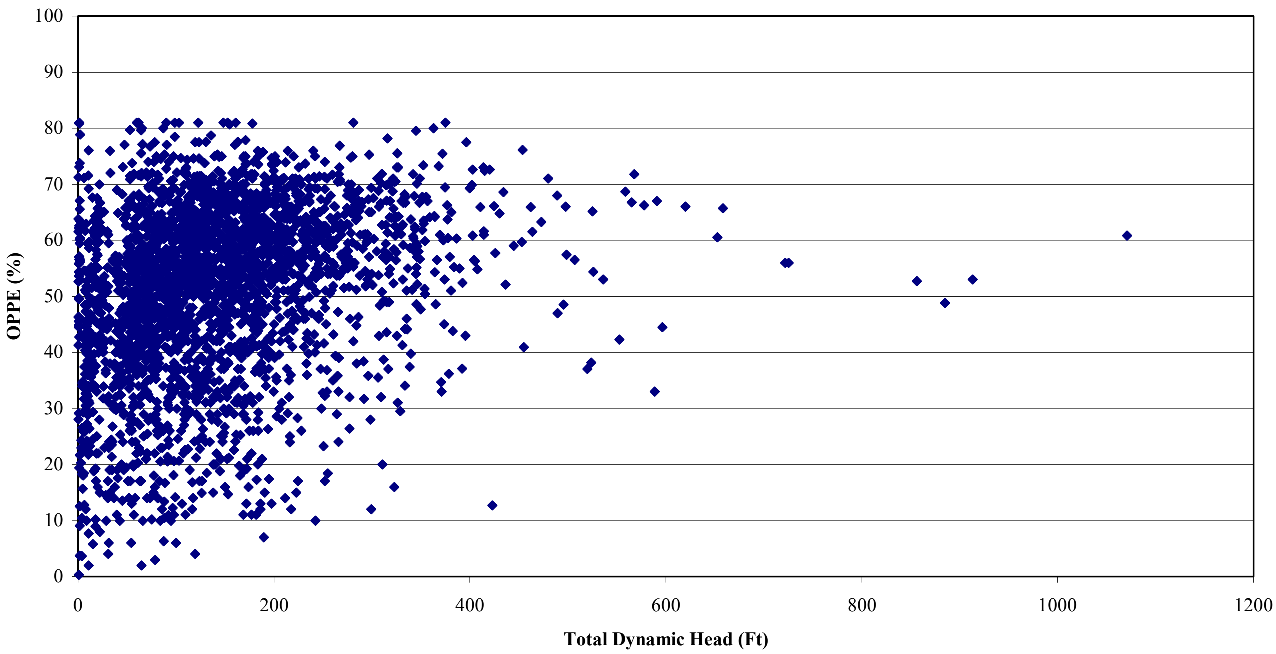


Figure D-4. Pump efficiency as a function of motor input kW for each pump tested

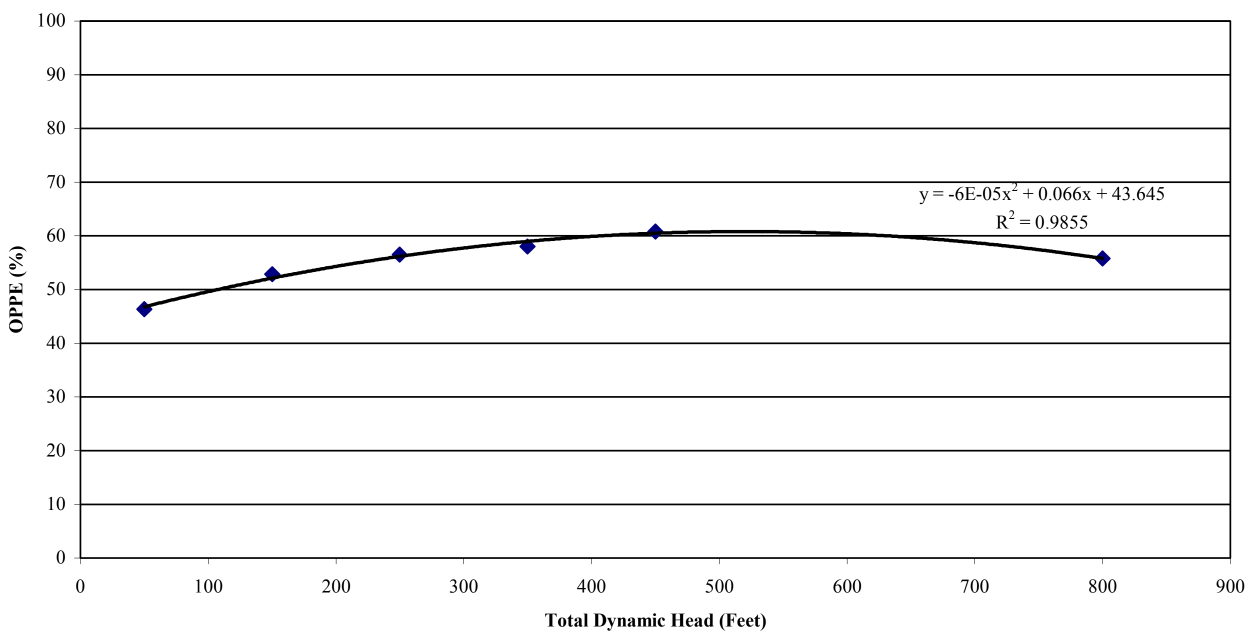


Figure D-5. Average on-farm overall pumping plant efficiency as a function of average TDH

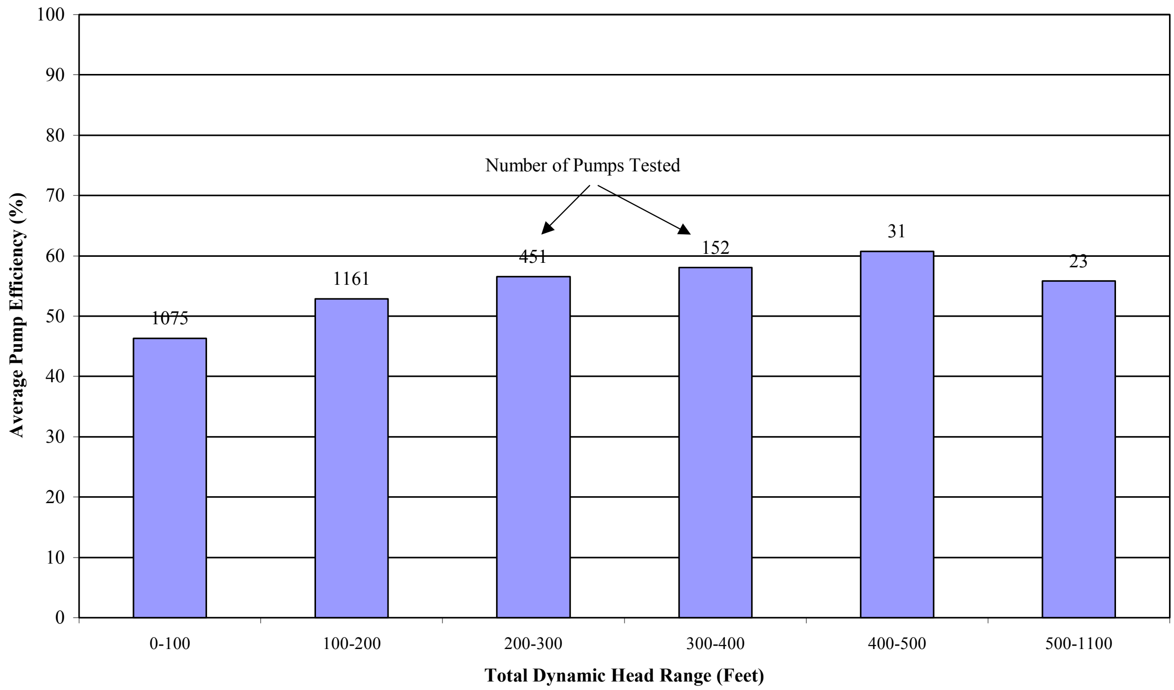


Figure D-6. Average overall pumping plant efficiency by TDH and the number of tests performed in each TDH range

ATTACHMENT E
Analysis of Irrigated Areas in Ranchettes

ATTACHMENT E
ANALYSIS OF IRRIGATED AREAS IN RANCHETTES

Urban sprawl into agricultural areas is occurring throughout California. In recent years, a popular form of urbanization is for developers to buy large parcels and split them into 1- to 8-acre parcels. Generally, one or two houses are built on these relatively large lots, termed “ranchettes”. The popularity of ranchettes has increased in suburban areas where the price of land is reasonable. Most of the owners commute to the cities for work and recreation but do not feel they live in the confined areas generally associated with urban or suburban housing.

Unlike complete urbanization of a region where lots can be a quarter to an eighth of an acre or smaller, ranchette areas are open and can be used to grow crops, raise horses, etc. The amount of area currently in ranchettes has not yet been defined; however, the California Department of Conservation Division of Land Resource Protection Farmland Mapping and Monitoring Program is currently completing a survey of Fresno, Madera, Merced, and Stanislaus counties as a pilot project to begin defining this area. Other important questions that must be addressed are:

- How is the conversion to ranchettes from irrigated agriculture going to affect the amount of applied water?
- What is the source of the water and is it different than the source of the irrigated agriculture that it replaced?
- How will the answers to the first two question impact energy requirements?

Applied Water

The difference in the amount of applied water for ranchettes versus large-scale irrigated agriculture depends on a number of variables. Some of these variables include:

- Irrigation efficiency
- Irrigated acreage
- Crop type and health
- Management

In all probability, the irrigation efficiency is going to decrease. Most ranchette owners do not have a farming or agricultural background and are growing crops as a hobby, not as an important part of their income. Management and irrigation efficiency are not going to be priorities. This will lead to an increase in applied water.

A more important factor may actually be whether or not the irrigated land is even being irrigated. To date, no known research has been conducted to analyze this question. ITRC conducted a brief GIS analysis of ranchette areas in Fresno, Tulare, Kern, and Sacramento counties to help answer this question.

The California Department of Water Resources (DWR) conducts land use surveys by county throughout the state. One of the identifiers used is Residential (UR), which differs from Urban (U) by the amount of land per parcel. UR is not limited to ranchettes; however, ranchettes fall into this category. Areas included in the UR category may not have more than 8 single family dwellings on 1 acre, a spatial definition that is smaller than what would be called a ranchette. However, despite the definition, for the most part the UR category is made up of 1 single family dwelling on 1- to 5-acre lots. The latest land use survey for each of the four counties sampled was used for the ranchette irrigated area analysis.

The land use surveys were obtained in shapefile format from the DWR. All land classified as UR was separated from the original survey and overlaid on 1-meter color aerial photos (DWR) using ArcView 3.2. However, while analyzing the data, it became difficult to determine whether or not the land was irrigated. For the most part, the ranchette areas seemed to be non-irrigated, but it was challenging to quantify a value.

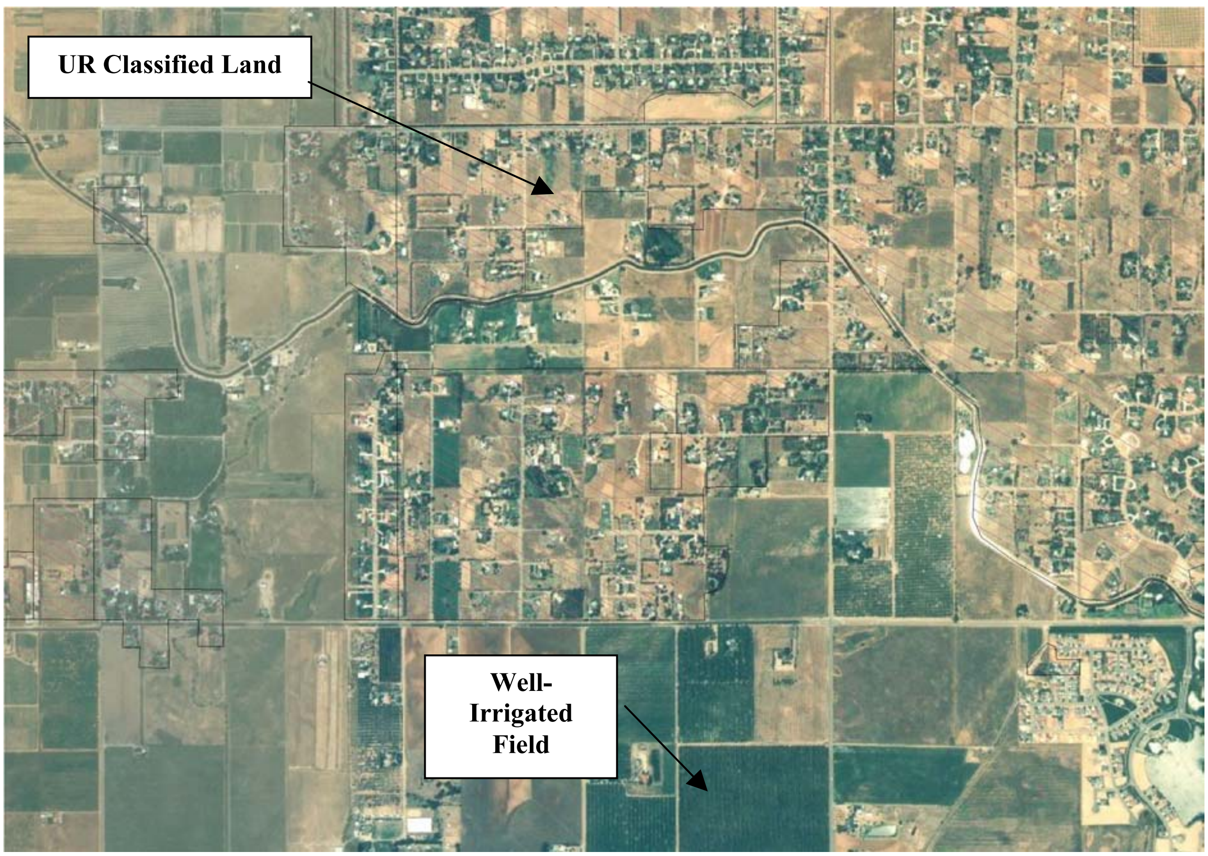


Figure E-1. An example of the DWR UR classified land overlaid on DWR color aerial photos near Clovis, CA

It was decided that LandSat 7 images taken during the beginning of August 2002 would be used for this analysis. Using LandSat's multiband images, the vegetative index can be calculated and used to quantify the irrigated versus non-irrigated UR land.

LandSat 7 images were obtained from the California Spatial Information Library (CaSIL) Calview program. Image bands 10, 20, 30, and 40 were downloaded and stacked using ArcView Image Analyst. These images have a resolution of 20 meters, which is much poorer than the 1-meter aerial photos. However, the accuracy is sufficient to estimate the percent of irrigated acreage.

First, the UR classified land shapefile was overlaid on the stacked LandSat image. Since the image has bands 30 and 40 (red and near infrared, respectively), it can be used to show natural or infrared (IR) color. In the natural color image, the more green the area, the healthier the vegetation. In the IR image, the areas that were green now show up as red.

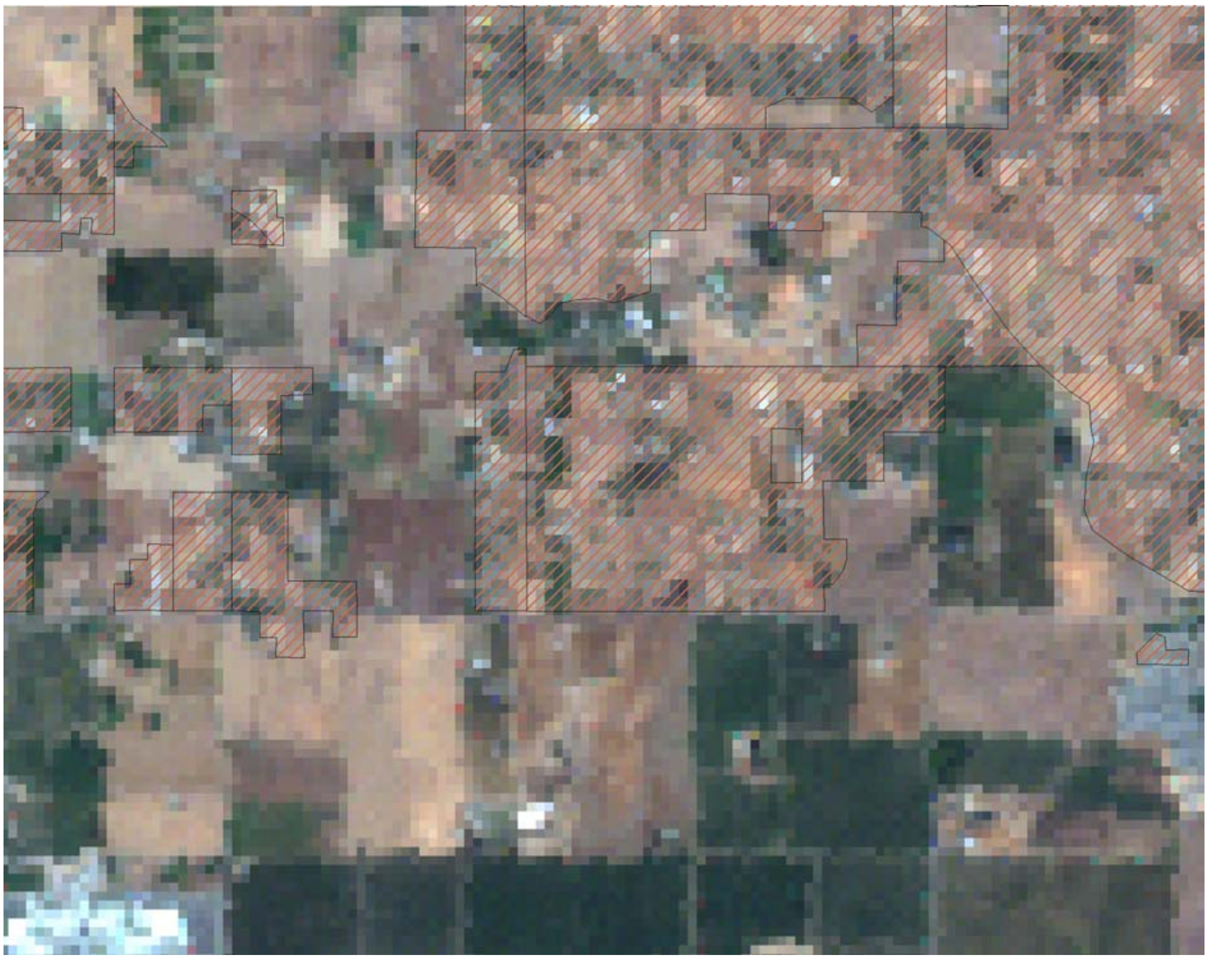


Figure E-2. Natural color LandSat image of the same area as Figure E-1

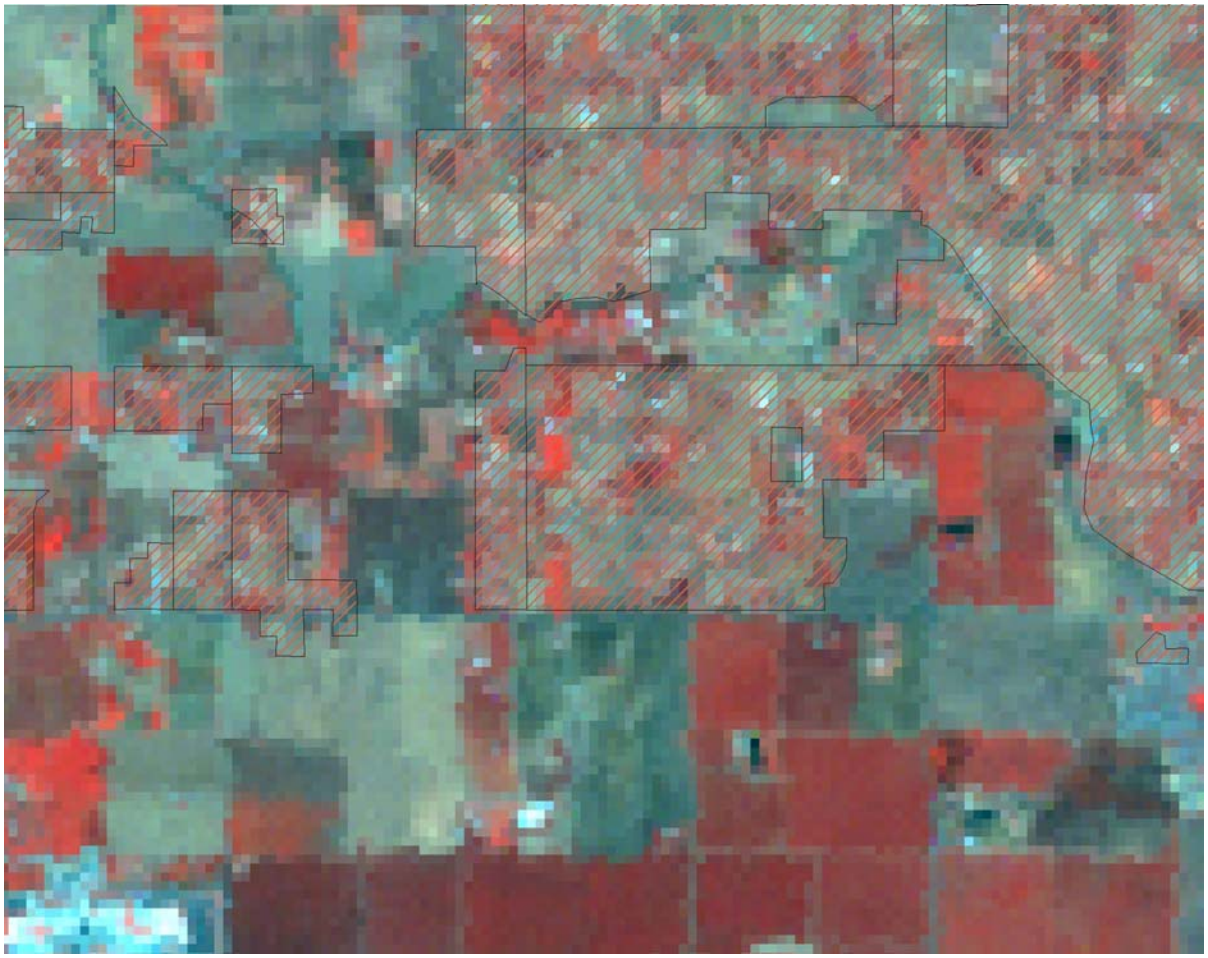


Figure E-3. LandSat image showing an infrared image of the same area as the first two images

Using ArcView Image Analyst, the Normalized Difference Vegetative Index (NDVI) was calculated. A grayscale image is created that shows land with healthy vegetation as white and as the health of the vegetation decreases, the pixels become darker. The equation used by the image analyst to calculate NDVI is ((IR-Red)/(IR+Red)). NDVI values range from 1 to –1. Pixels representing healthy vegetation have positive values approaching 1; bare soil, road, and urban areas have values around 0. Open water and clouds have negative values approaching –1.

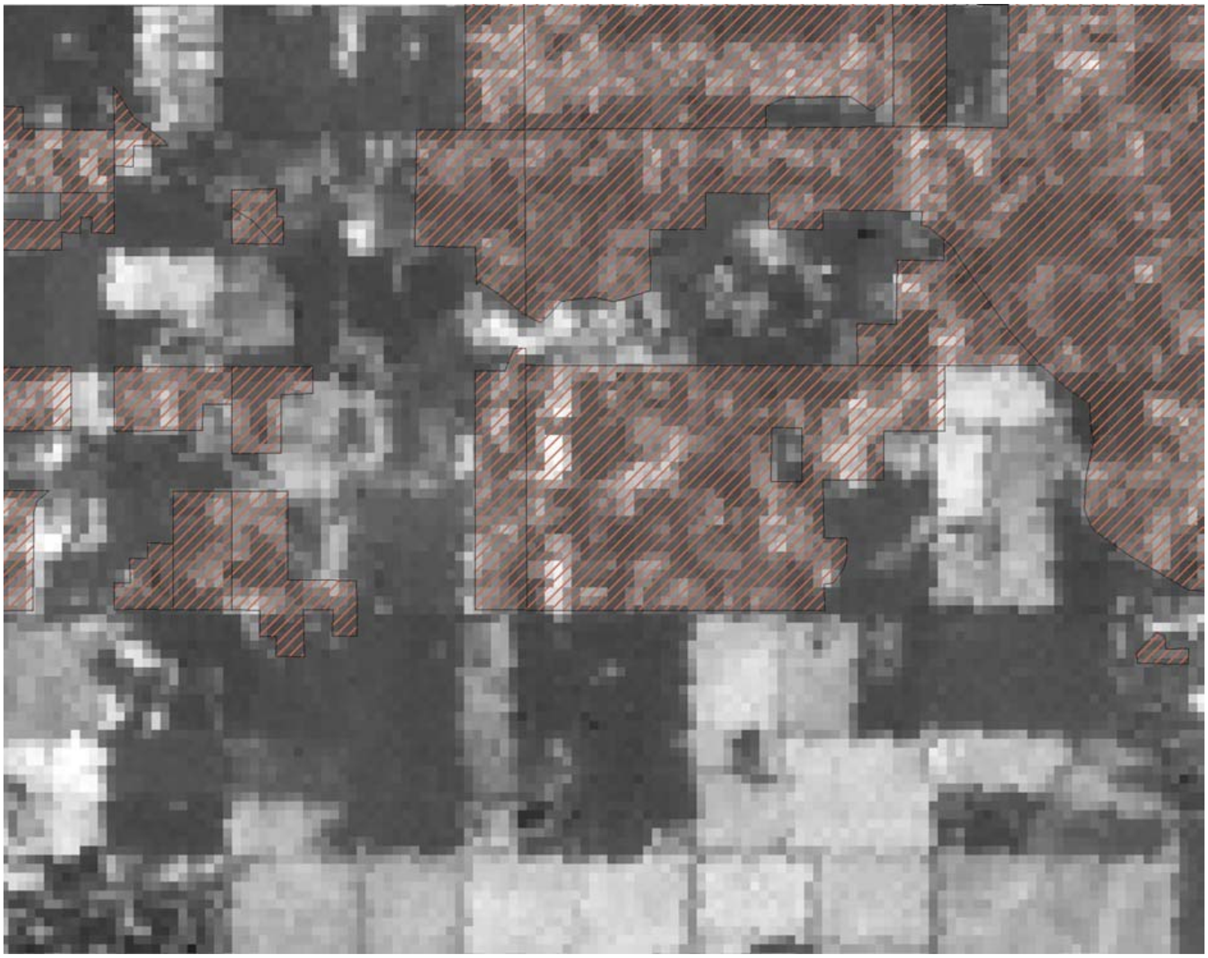


Figure E-4. Normalized Difference Vegetative Index image of the area in the previous images. The light gray-white indicates healthy vegetation.

The NDVI image is then classified, where pixel values are grouped into a range. Since the LandSat images used were taken in August, rain fed pasture and natural vegetation would be dead and would show up as a darker pixel. Only the light gray-white pixels indicate healthy vegetation.

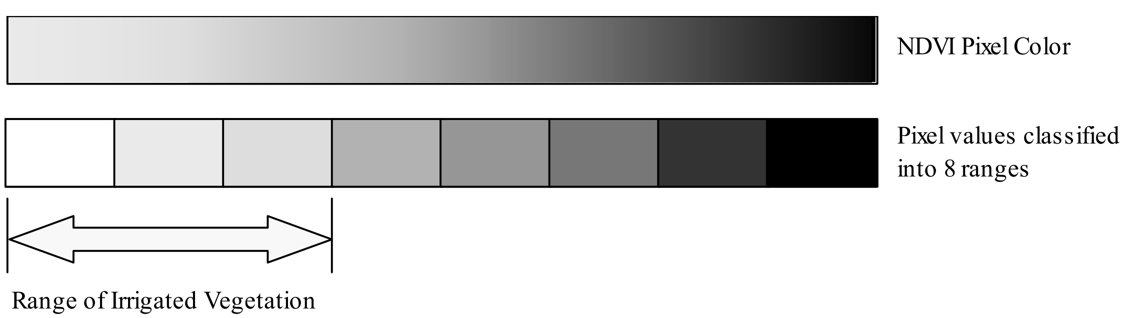


Figure E-5. Schematic of how NDVI pixels are classified. The three lightest colored ranges are classified as irrigated vegetation.

Once the classification or grouping is completed using ArcView Image Analyst, the new classified image can be used to determine the area in each grouping. Using the DWR UR land survey shapefile overlaid on the classified image, ArcView Image Analyst neglects the areas that are not covered by the shapefile and only the area classified as UR is examined. The table below shows the estimated UR acreage by classification. The acreage values do not indicate total ranchette acreage; rather, the acreage classified by the DWR as UR.

Table E-1. Irrigated acreage analysis for ranchettes using ArcView GIS and ArcView Image Analyst

	Vegetative Index Classification								Total Sample	Total Irrigated	Percent Irrigated Vegetation
	8	7	6	5	4	3	2	1			
Region	**Acres**	**Acres**	**Acres**	**Acres**	**Acres**	**Acres**	**Acres**	**Acres**	**Acres**	**Acres**	
Fresno	**54**	**519**	**1,222**	2,156	3,033	4,795	4,268	487	**16,533**	**1,795**	**11%**
Kern	**62**	**243**	**433**	733	1,155	1,770	2,765	1,180	**8,340**	**738**	**9%**
Sacramento	**88**	**247**	**477**	969	1,707	3,534	7,801	1,046	**15,869**	**813**	**5%**
Tulare	**126**	**450**	**661**	1,017	1,467	2,096	1,809	252	**7,878**	**1,237**	**16%**
	Irrigated Vegetation										

Source of Applied Water

The second question with regards to ranchettes is what the source of the irrigation water is. Without extensive ground truthing, this question is difficult to answer. The DWR land use survey completed for Fresno County in 1994 did classify the water sources for some of the land. However, the majority of the land classified as UR did not have a classification for water source. The UR land that had a water source classification was said to have surface water as the main source.

Table E-2. DWR classified source of irrigation water for sampled acreage in Fresno County

Water Source	**Sample Size Acres**	**Percent of Total**
Surface	5,748	35%
Mixed Surface and Groundwater	1,883	11%
Groundwater	163	1%
Unclassified	8,739	
Total Sample Acreage	**16,533**	

The accuracy of the data in the table above is suspect. The DWR does ground truth all surveys; however, how the surveyors determine the water source is unknown. With a significant amount of acreage utilizing surface water, it would seem that more UR acreage would be irrigated. If, however, the surveyors simply assumed surface irrigation was the source because of the proximity of the land to a surface water source (irrigation district canal), the area actually able to utilize surface water may be much different. Just because a surface supply is near the parcels does not mean the ranchette owners have the ability to use this water.

It is entirely possible that ranchette owners do not have a supply source sufficient to irrigate their entire parcel. Generally, a groundwater well for a house does not have the capacity to irrigate more than typical landscaping. Treated city water is too expensive and drilling a well specifically for irrigation may not be cost effective for hobby farming. This would explain why such a small amount of UR land had irrigated vegetation.

ATTACHMENT F
Groundwater Banking Case Studies

ATTACHMENT F
GROUNDWATER BANKING CASE STUDIES

Arvin-Edison Water Storage District

The Arvin-Edison WSD is located in the southern end of the San Joaquin Valley. The initial source of water for the district was from groundwater. Consumptive use was greater than the recharge, so the aquifer was in overdraft. Supplemental water was brought into the district in the late 1960's by way of the Friant-Kern Division of the Federal Central Valley Project to counteract the overdraft conditions. The amount of imported water would vary from as low as 10,000 acre-feet in dry years (such as 1977) to over 350,000 acre-feet in very wet years. Since the district did not have any surface storage capability, groundwater recharge was done during wet years so the water would be available during dry years. Arvin-Edison WSD, therefore, was operated as a true conjunctive use district.

Other agreements were developed over time as new methods for bringing in imported water to the southern San Joaquin Valley were developed. Still, the main mode of operation for the district is conjunctive use. The district has gained much experience in developing spreading works and well fields for the storage and recovery of imported water.

The aquifer is well defined, with impermeable rock to the south and east and a groundwater gradient sloping into the district from the north and west. Therefore, there is very little water lost due to lateral flow when the groundwater is recharged. The surface to the aquifer is moderately permeable so the recharge rate of the spreading basins is relatively fast. The aquifer has a comparatively high hydraulic conductivity, which allows the relatively fast recovery of groundwater from the well fields. These recharge and recovery characteristics, plus the availability of aquifer storage space from years of overdraft, gives Arvin-Edison WSD desirable physical conditions to participate in a groundwater banking program.

In 1997, Arvin-Edison WSD entered into an agreement with MWD to bank approximately 250,000 acre-feet of MWD State Water Project Supply and return the water in dry years. MWD can request an amount to be returned for a certain year, but Arvin-Edison WSD has the discretion to determine when the water is returned. The agreement states that the water "…will be returned during off-peak times so as not to interfere with normal, historic District operations" (quote from The Arvin-Edison Water Storage District Water Resources Management Program, April 2003). MDW provided all the funding ($25 million) needed to construct the new facilities to enable the "put" and "take" of the banking program, including an additional 500 acres of spreading basins, 15 new wells, and a 4½ mile pipeline connecting the district's south canal with the California Aqueduct.

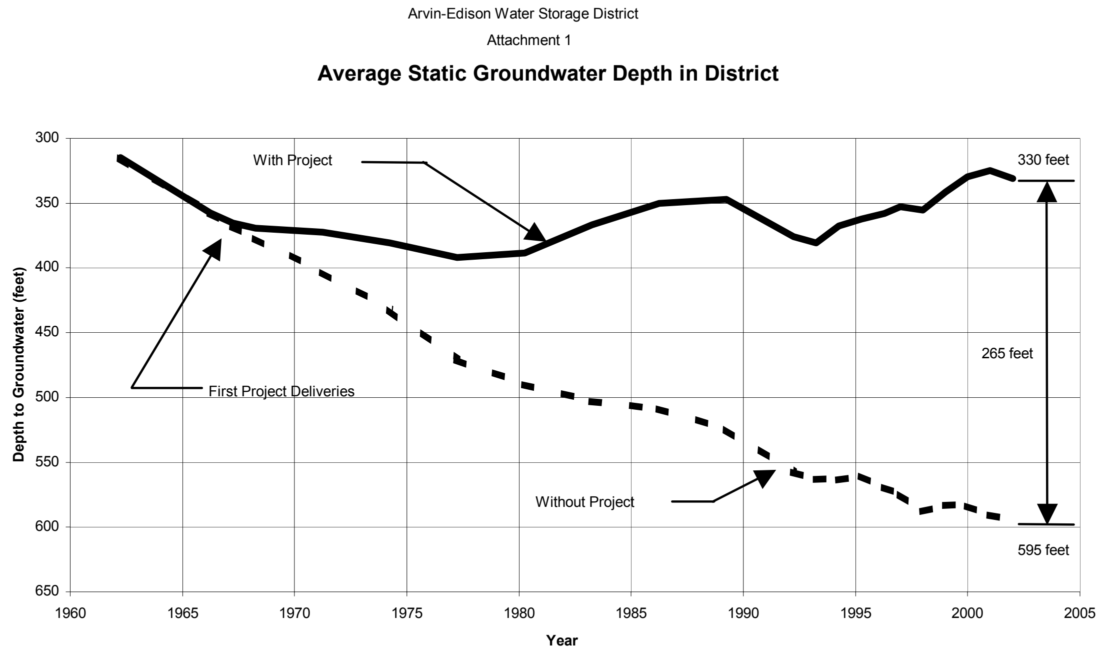


Figure F-1. Historical groundwater level graph provided by Arvin-Edison WSD

The effect of importing water is clearly shown in the figure above. The groundwater banking program with MWD is also evident in this figure, with the increase in water level around the year 2000 attributed to the banking program.

The financial support from MWD not only facilitates the groundwater banking program since the district is also able to use the pumping and spreading facilities for district operations. Therefore, the district now has an increased ability to store excess runoff during wet years, as well as the ability to recover groundwater for district use.

Energy Component

MWD has several options for storing water in the Arvin-Edison WSD, including in lieu exchanges. In general, however, the water stored by MWD in Arvin-Edison WSD will be delivered down the California Aqueduct. The water would then cross over to the eastern side of the San Joaquin Valley through the Cross Valley Canal to the Forrest Frick pumping plant. From that point, the water would be pumped up to the district to the spreading basins. The total energy required to "put" the water into the district's aquifer is around 500 KWh/AF.

The energy required to "take" water from the district is an average of 775 KWh/AF to pump the water to the surface, and 45 KWh/AF to pump the water through the 4½ mile pipeline back to the California Aqueduct. The water is delivered to the California Aqueduct downstream (uphill) of the Buena Vista pumping station, bypassing an energy requirement of 242 KWh/AF. The net energy required to "take" the water out of the district would then be (775 + 45 – 242) KWh/AF, or about 580 KWh/AF. The total energy required for both "put" and "take" is then approximately (500 + 580) KWh/AF, or 1080 KWh/AF.

For a sense of magnitude, MWD budgets 3,000 KWh/AF as the energy required to deliver State Project water from the Delta to Southern California (including regeneration). The groundwater banking program with Arvin-Edison WSD would add an additional 1080 KWh/AF.

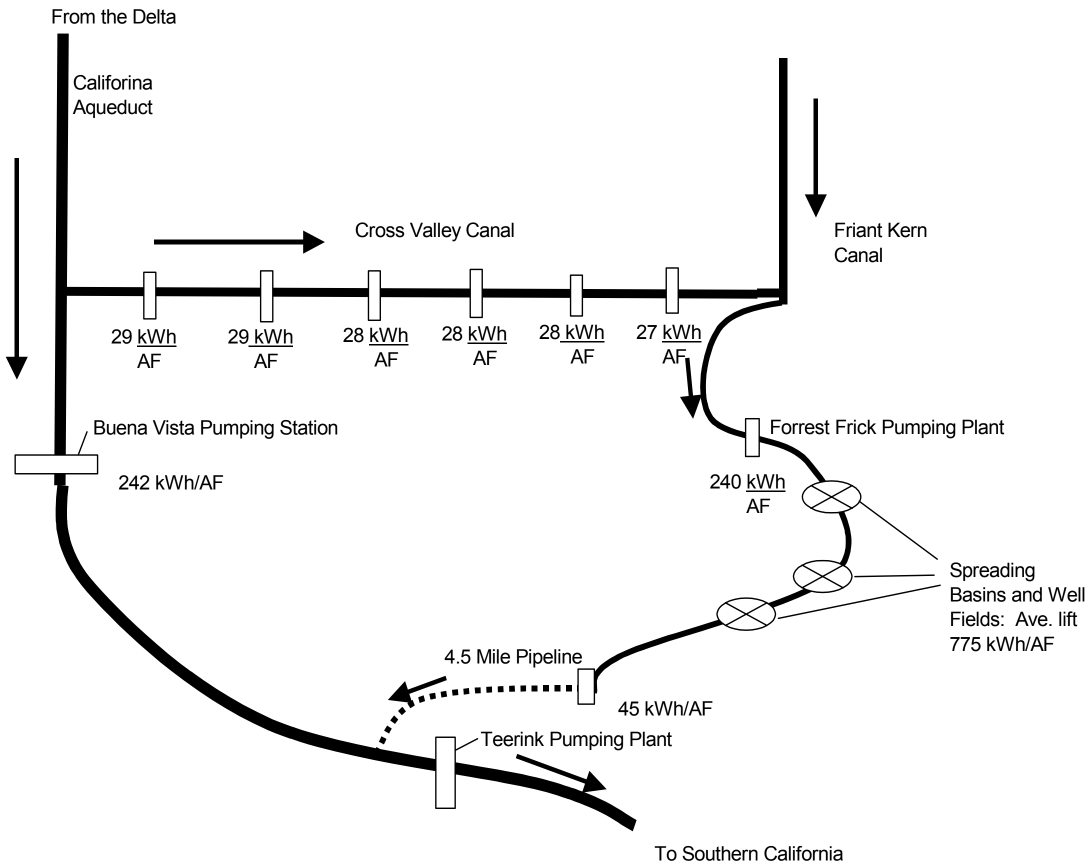


Figure F-2. Schematic of the Arvin-Edison WSD groundwater banking program

Kern County Water Agency (KCWA)

The KCWA was created in 1961 for the primary purpose of importing water into Kern County. It acts as the wholesaler of water, including State Project water, with its stakeholders (Kern County water districts and the city of Bakersfield) acting as the retailers. KCWA has an annual entitlement of one million acre-feet of water from the State Water Project (SWP), which represents 25 % of the total SWP. The Kern River, a federal project (Central Valley Project) and groundwater are other water sources for KCWA, which results in a total of approximately 3.2 million acre-feet of applied water. Arvin-Edison WSD and Semitropic WSD are stakeholders in the KCWA.

Groundwater banking is the primary way in which KCWA regulates seasonal and year-to-year variations in storm runoff and the importation of water. The KCWA controls and manages (both directly and indirectly) a variety of projects that include both direct recharge and in lieu projects. The bulk of the direct recharge projects are physically located on the Kern River Fan west of the city of Bakersfield. The geologic conditions of the Kern River Fan are good for groundwater banking since there is a relatively high hydraulic conductivity for both direct recharge and recovery (put and take) for a large aquifer.

The KCWA does not directly have transfer agreements with stakeholders outside of Kern County; however, other participants under the umbrella of KCWA may have such arrangements with water banked in the KCWA projects. The table below shows the scope of groundwater banking projects that KCWA is directly or indirectly involved with.

Table F-1. Data on groundwater banking projects in Kern County provided by KCWA

Project	Gross Area (Acres)	Date Operational	Maximum Annual Recovery (AF)	Maximum Annual Recharge (AF)	Estimated Defined Storage (AF)
Direct Recharge Projects					
Berrenda Mesa	369	1983	46,000	58,000	200,000
COB 2800 Acres	2,760	1978	46,000	168,000	800,000
Kern Water Bank	19,900	1995	287,000	450,000	1,000,000
Pioneer	2,273	1995	123,000	146,000	400,000
West Kern WD/Buena Vista WSD	2,000	1978	30,000	75,000	300,000
Subtotal	**27,302**		**532,000**	**897,000**	**2,700,000**
In Lieu/Direct Recharge Projects					
Arvin-Edison WSD/MWD	130,000	1998	40,000	140,000	250,000
Semitropic WSD/MWD	221,000	1990	223,000	315,000	1,000,000
Rosedale-Rio Bravo WSD	40,000	2003	15,000	80,000	200,000
Buena Vista WSD	50,000	2002	50,000	105,000	400,000
Kern Delta Water District/MWD	125,000	2004	50,000	50,000	250,000
Subtotal	**566,000**		**378,000**	**690,000**	**2,100,000**
Total	**593,302**		**910,000**	**1,587,000**	**4,800,000**

The COB (City of Bakersfield), Kern Water Bank and Pioneer direct recharge projects are a major part of the KCWA banking program, as shown in **Figure G-3**. Most of the area in these projects is open ground (not farmed). A major portion of this area, the Kern Water Bank, was previously private farmland. When this area became a groundwater banking project, farming operations ceased and the existing wells were taken over by the project. Further wells were constructed as needed to operate the groundwater banks to their desired capacity.

Energy Component

Water is "put" into these groundwater bank spreading basins by gravity. The "take" energy requirement is primarily the pumping requirement to bring the water to the surface. Therefore, the major energy component is a function of the well pump lift and the well pump efficiency. KCWA pays close attention to its well pump efficiencies (as do Arvin-Edison WSD and Semitropic WSD). One of the limiting factors in well pump efficiency is when the peak efficiency is designed for the lowest anticipated water table level (highest pump lift), but the water table is usually kept higher than this level as part of the groundwater banking program. The rationale behind this is that it is better to have a higher efficiency when the energy requirement is the highest. There may be potential to mitigate this problem with the use of variable speed control.

The figure below was provided by KCWA and shows the general condition of the Kern River Fan aquifer over time and how the groundwater banking programs influence the aquifer.

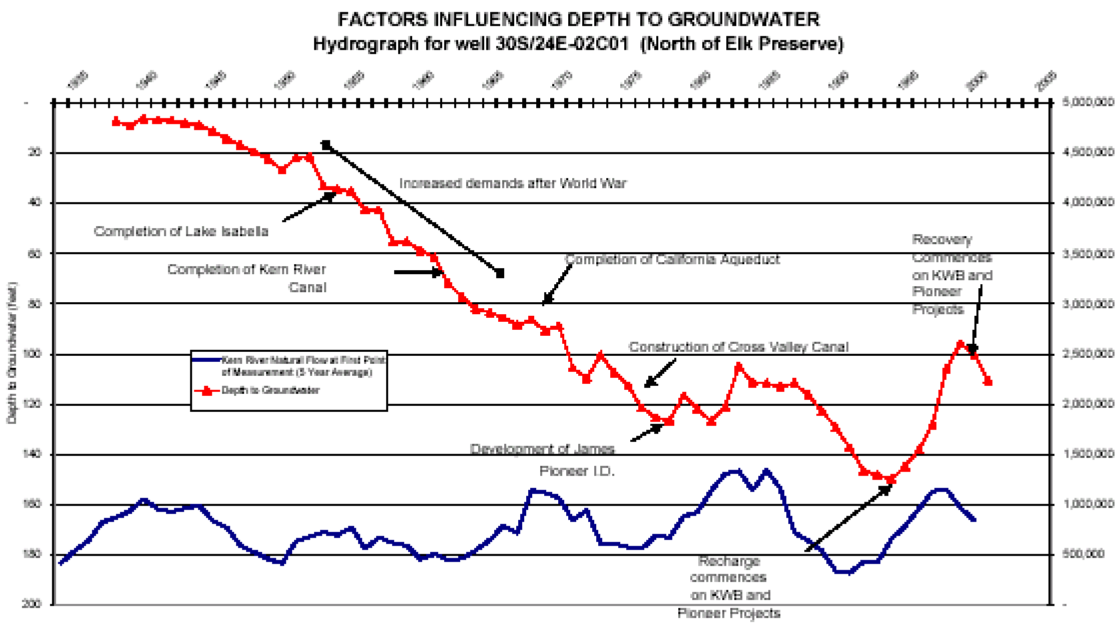


Figure F-3. Graph provided by KCWA showing aquifer changes over time

As stated earlier, the average energy requirement to operate the groundwater banking projects on the Kern River Fan is approximately 400 KWh/AF. The actual energy required for any given well over a period of time is obviously related to the water table depth. From the figure above, and from discussions with KCWA personnel, the water table depth would be much lower without the groundwater banking program. However, as Rick Iger of KCWA pointed out and as stated on the previous page, pumping efficiency may actually decrease with a decrease in pump lift, or TDH (Total Dynamic Head). Since the system curve involves bringing the water to the surface only and does not require pressurizing the water above the level of the ground, the TDH decreases almost directly proportionally to the decrease in pumping depth (column losses do increase as flow rate increases, however). An analysis of Well #3 pump curves provided by KCWA shows that if the water table were to rise from the present 150 ft, with a corresponding energy requirement of 270KWh/AF, to around 75 feet, the pump efficiency would start to fall off dramatically, resulting in an energy requirement of 233 KWh/AF. Therefore, the gain in water level would not translate to energy savings as significant as might be expected.

It should be noted, however, that if the water level for pump #3 were to drop below 150 ft, the system curve for the pump would actually move toward higher efficiency. Maximum efficiency is approximately at a TDH of 240 ft., which would correspond to a water table depth of over 200 ft.

Semitropic Water Storage District (Semitropic WSD)

Semitropic WSD is in a region that traditionally used groundwater for irrigation. The district was in overdraft until surface water from the State Water Project (SWP) began being imported in the early 1970's. Although the decline of the water table slowed appreciably with the import of SWP water, the district was still facing long term overdraft.

Semitropic WSD developed facilities so that it could operate under the conjunctive use method, where surface water is used when available (more used in wet years, less in dry years) with any shortfall made up with groundwater. With the way the district was developed, not all of the land in the district was able to utilize surface water. That fact, combined with the lower relative hydraulic conductivity (low percolation rates), limited the ability of Semitropic WSD to take advantage of surplus water during wet years. To increase their surface water delivery facilities, Semitropic WSD entered into a groundwater banking agreement with MWD, Santa Clara Valley Water District and others to bank up to 1,000,000 acre-feet of water.

The primary method for "put" and "take" by the banking partners was to be in lieu exchange. This would mean that the overlying landlords would forgo using well water and use surface water when a banking partner "put" water into the groundwater bank. When a banking partner wanted to "take" water from the groundwater bank, the partner would simply use SWP water that was entitled to the district and the overlying landowners would use well water in a "bucket for bucket" exchange (minus an agreed-to percentage for delivery and other losses). The banking partners, however, also wanted to be able to physically recover water out of the groundwater bank for times when surface water would not be available. Therefore, it was agreed that the district would have a pump-back capacity of 90,000 acre-feet per year. The total "take" possible in a year would then be 90,000 acre-feet of direct extraction (pump-back) and from zero to 133,000 acre-feet of in lieu transfer. In a dry year, no SWP water may be available, so the maximum "take" would be 90,000 acre-feet. In a wet year, up to 133,000 acre-feet of SWP might be available, but not needed by the banking partners, so the maximum of 223,000 acre-feet would rarely be realized.

New surface delivery facilities needed to be constructed in order to bring the water to a larger area than before the groundwater banking project. Facilities to pump back the water also needed to be constructed. First, a combined ability to receive surface water during times of recharge and to be able to pump well water back to the district canals was needed for the areas directly participating in the groundwater banking project. Reversing the flow in the main delivery canals through the use of gates and pumps creates the pump-back ability up to the Vido G. Fabbri Hydro Turbine Pumping Plant. At this point the water must be lifted up 60 feet to the California Aqueduct (TDH of 115 feet). The Vido G. Fabbri Hydro Turbine Pumping Plant also generates electricity. This generating capacity essentially matches the canal pumping energy requirement to reverse the canal flow.

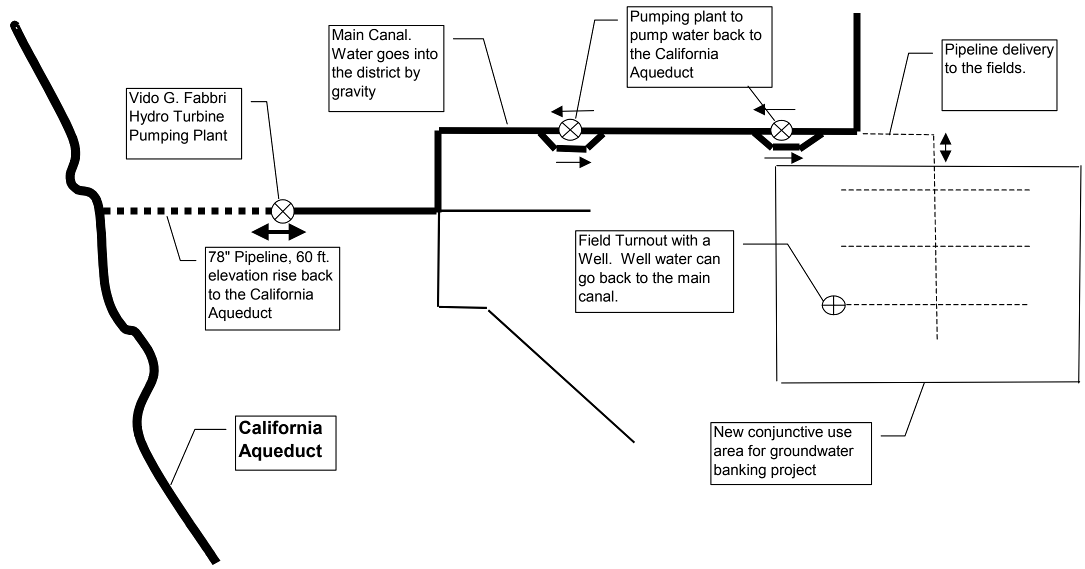


Figure F-4. Semitropic WSD general schematic of groundwater banking plumbing

Energy Component

The energy component of the "put" for the Semitropic WSD is essentially zero. Energy is generated at the Vido G. Fabbri Hydro Turbine Pumping Plant through the 850 kW turbine. This essentially balances with the energy required to pump the water through the pipelines off the main delivery canal to the field turnouts.

The "take" energy component includes the lift at the farmer's pump from the dynamic pumping level back to the main canal, plus the 12-foot lift required to cause the main canal to flow back to the California Aqueduct, and the 115 ft. TDH required to pump up to the California Aqueduct at the Vido G. Fabbri Hydro Turbine Pumping Plant. In 2001, Semitropic WSD charged its banking partners an energy charge based on 650 KWh/AF for water returned by "pump-back" and 485 KWh/AF for in lieu water. The in lieu water energy charge is essentially the cost of the well used by the farmer instead of the farmer taking surface water.

The effect of banking 1,000,000 acre-feet within the Semitropic WSD has been to raise the water table almost 45 feet higher than it would have been without the project (as of 2002). The facilities to deliver surface water and return groundwater from participating landowners, including pumping and piping from the main canal to the fields, the pump lifts along the main canal to allow water to flow back to the California Aqueduct, and the Vido G. Fabbri Hydro Turbine Pumping Station, were funded by the banking partners. The facilities for the groundwater banking project also allows the district to take greater advantage of surplus water during wet years for conjunctive use that wouldn't have been possible without the project. Therefore, the net effect of the groundwater banking project on the water table might be greater than simply the amount of water banked.

Figure F-5. Pumping location on main delivery canals

Surface water from the main canal to participating groundwater banking landowners needs to be pumped through a pipeline system. Return flow for "take" by banking partners is accomplished by having well water flow back to the main canal through the same pipelines.

Figure F-6. Typical configuration of a field turnout

Field turnouts have been modified to allow irrigation to be done using either surface water brought to the field through the district pipeline system from the main canal, or with groundwater. Well water can also be injected directly into the district pipeline system and returned to the main canal.

Figure F-7. The Vido G. Fabbri Hydro Turbine Pumping Plant

The Vido G. Fabbri Hydro Turbine Pumping Plant includes an 850 KW hydro turbine (not shown) to generate electricity when water from the California Aqueduct flows into the district (60 ft. elevation drop from California Aqueduct to the hydro turbine). When water is returned to the California Aqueduct, the pumping plant shown above is used. The district removes some of the pumps (notice some of the discharge pipes do not have pumps attached) for use in other parts of the district when there are only inflows into the district and no outflows.

ATTACHMENT G
Net Energy Cost of a Groundwater Banking Program

ATTACHMENT G
NET ENERGY COST OF A GROUNDWATER BANKING PROGRAM

Arvin-Edison WSD is used as an example for examining the potential effect on energy use due to a groundwater banking program. An estimate of the potential energy savings per year due to a higher water table is determined and then compared to the annual energy required for the basic operation of the groundwater bank.

Arvin-Edison WSD is comprised of approximately 132,000 acres. The aquifer under the district is mostly isolated, so it will be assumed that all the water "put" in by a banking program stays within the district. Two other assumptions are made for this exercise:

1. The Specific Yield of the aquifer is 0.12 ($ft.^3$ water/ $ft.^3$ soil).
2. The water table remains level as it rises and falls.

The Arvin-Edison WSD has an agreement with MWD for a water bank storage of 250,000 AF (nominal). If the full 250,000 AF is "in the bank" (that is, no recovery has taken place), the water table would rise almost 16 feet from where it would have been without the banked water. Therefore, the district wells would have 16 fewer feet in lift when all 250,000 AF is in storage.

District Annual Pumping Energy Requirements

Over the past 20 years, the average amount of water delivered to approximately 40% of the district that receives water directly from the district distribution system was 148,848 AF. Of this 148,848 AF, an average of 34,011 AF was pumped from the aquifer using district wells, with the remaining water coming from outside surface water.

The remaining 60% of the district gets its irrigation water directly from private wells. Assuming the application amount per acre is the same as the areas receiving district water, this would equal 220,000 AF of groundwater pumped. Therefore, the district as a whole would pump an average of 254,000 AF a year from both private and district wells.

Estimated Annual Energy Savings

The net effect of the full 250,000 AF of MWD water in storage for pumping an average of 254,000 AF per year is an energy savings of around 7 million KWh per year (or 7,000 MWh/Year):

1. It takes 1.02 KWh to pump 1 AF up 1 foot at 100% efficiency.
2. Assuming a 60% efficiency, it would take (254,000 AF x 1.02 KWh/AF-ft x 16 ft)/60% = 6,930,133 KWh or approximately 7,000,000 KWh. 1 megawatt (MW) = 1,000 kilowatts, so 7,000,000 KWh = 7,000 MWh.

It can be assumed that all 250,000 AF will not be in storage at any given time. During dry years, the banking partner (MWD) may want to "take" water and during wet years the banking partner may want to "put" water. It is assumed that the energy reduction benefit from the groundwater bank will be directly proportional to the amount stored in the bank.

Table G-1. Arvin-Edison energy savings due to a higher water table

Water Table Increase, ft.	Annual Energy Savings for Groundwater Pumping, Megawatt-hours
16	7,000
12	5,250
8	3,500
4	1,750

Estimated Annual Energy Requirement

The "take" rate (recovery capacity) is estimated to range from 40,000 to 75,000 AF per year (from *Designing Successful Groundwater Banking Programs in the Central Valley*, The Natural Heritage Institute, 2001). The average annual "take" rate is assumed to be 60,000 AF, with 40,000 AF the minimum and 75,000 AF the maximum.

The resulting annual energy requirement for basic operation of the groundwater bank for the average annual "take" would be 60,000 AF/year x 1,100 KWh/AF = 66 million KWh/year or 66,000 MWh/Year. Since it will not be necessary to "take" water each year it was assumed that a "take" would occur 3 out of 10 years. This is roughly a magnitude of 2 to 10 times what might be expected for the energy savings due to a higher water table.

Table G-2. Arvin-Edison WSD annual energy required for a given annual "take"

Annual "Take" by MWD, (acre-feet)	Estimated Annual Energy Requirement for Basic Operation during the "take" year, Megawatt-hours	Estimated Average Annual Energy Requirement for Basic Operation assuming 3 "take" years out of 10, Megawatt-hours
40,000	44,000	13,200
60,000	66,000	19,800
75,000	82,500	24,750

ATTACHMENT H
Glossary of Groundwater Banking Terms

ATTACHMENT H
GLOSSARY OF GROUNDWATER BANKING TERMS

Active recharge Recharge (put) of a groundwater basin is accomplished by using spreading basins, injection wells, or surface delivery to overlying land.

Banking partner A stakeholder, who is not an overlying landowner and who does not have a historical right to existing groundwater from a given area, who provides a volume of water from an outside source not hydraulically connected to the aquifer for later removal.

Groundwater banking The right to export, with conditions, groundwater from an aquifer, including in lieu water, by an outside party (non-overlying user), at a volume not to exceed the amount put into the aquifer from an outside source.

In lieu Recharge (put) of a groundwater basin is accomplished through substitution of surface water for existing groundwater usage. Extraction (take) is accomplished by overlying landowners substituting groundwater for entitled surface water. The surface water that the overlying landlord was entitled to would then be redirected to the banking partner.

In situ Native or existing groundwater.

Put Water "deposited" in the groundwater bank either by active recharge or in lieu substitutions.

Reoperation The lowering of the water level in a reservoir below the normal (based on past reservoir management practices) operating level, with the released water stored as groundwater for later recovery by the beneficiaries of the reservoir. The lower water level in the reservoir allows the reservoir management the potential to store more water during peak inflows.

Take Water "withdrawn" from the groundwater bank either by exporting groundwater or in lieu substitutions.

Definitions from California DWR Bulletin 118 (update 2003)

Aquifer A body of rock or sediment that is sufficiently porous and permeable to store, transmit, and yield significant or economic quantities of groundwater to wells and springs.

Aquitard A confining bed and/or formation composed of rock or sediment that retards but does not prevent the flow of water to or from an adjacent aquifer. It does not readily yield water to wells or springs or store groundwater.

Artificial recharge The addition of water to a groundwater reservoir by human activity, such as putting surface water into dug or constructed spreading basins or injecting water through wells.

Available groundwater storage capacity The volume of a groundwater basin that is unsaturated and capable of storing groundwater.

Conjunctive use The coordinated and planned management of both surface and groundwater systems in order to maximize the efficient use of the resource; that is, the planned and managed operation of a groundwater basin and a surface storage system combined through a coordinated conveyance infrastructure. Water is stored in the groundwater basin for later and planned use by intentionally recharging the basin during years of above-average water supply.

Groundwater basin An alluvial aquifer or a stacked series of alluvial aquifers with reasonably well-defined boundaries in a lateral direction and a definable bottom.

Groundwater budget A numerical accounting, the *groundwater equation*, of the recharge, discharge and changes in storage of a aquifer, part of an aquifer, or a system of aquifers.

Groundwater in storage The quantity of water in the zone of saturation.

Groundwater management The planned and coordinated management of a groundwater basin or portion of a groundwater basin with a goal of long-term sustainability of the resource.

Groundwater management plan A comprehensive written document developed for the purpose of groundwater management and adopted by an agency having appropriate legal or statutory authority.

Groundwater mining The process, deliberate or inadvertent, of extracting groundwater from a source at a rate in excess of the replenishment rate such that the groundwater level declines persistently, threatening exhaustion of the supply or at least a decline of pumping levels to uneconomical levels.

Groundwater monitoring network A series of monitoring wells at appropriate locations and depths to effectively cover the area of interest. Scale and density of monitoring wells is dependent on the size and complexity of the area of interest.

Groundwater overdraft The condition of a groundwater basin in which the amount of water withdrawn by pumping exceeds the amount of water that recharges the basin over a period of years during which water supply conditions approximate average conditions.

Groundwater recharge facility A structure that serves to conduct surface water into the ground for the purpose of replenishing groundwater. The facility may consist of dug or constructed spreading basins, pits, ditches, furrows, streambed modifications, or injection wells.

Groundwater recharge The natural or intentional infiltration of surface water into the zone of saturation.

Groundwater storage capacity Volume of void space that can be occupied by water in a given volume of a formation, aquifer, or groundwater basin.

Groundwater table The upper surface of the zone of saturation in an unconfined aquifer.

Groundwater Water that occurs beneath the land surface and fills the pore spaces of the alluvium, soil, or rock formation in which it is situated. It excludes soil moisture, which refers to water held by capillary action in the upper unsaturated zones of the soil or rock.

Hydraulic conductivity A measure of the capacity for a rock or soil to transmit water; generally has the units of feet/day or cm/sec.

Hydrograph A graph that shows some property of groundwater or surface water as a function of time.

Infiltration The flow of water downward from the land surface into and through the upper soil layers.

Infiltration capacity The maximum rate at which infiltration can occur under specific conditions of soil moisture.

Irrecoverable losses The water lost to a salt sink or lost by evaporation or evapotranspiration from a conveyance facility or drainage canal, or in the fringe areas of a cultivated field.

Natural recharge Natural replenishment of an aquifer generally from snowmelt and runoff; through seepage from the surface.

Operational yield An optimal amount of groundwater that should be withdrawn from an aquifer system or a groundwater basin each year. It is a dynamic quantity that must be determined from a set of alternative groundwater management decisions subject to goals, objectives, and constraints of the management plan.

Overlying right A mutual right of property owners above a common aquifer to the reasonable and beneficial use of a groundwater resource on land overlying the aquifer from which the water is taken. Overlying rights are correlative (related to each other) and overlying users of a common water source must share the resource on a pro rata basis in times of shortage. A proper overlying use takes precedence over all non-overlying uses.

Perennial yield The maximum amount of water that can be withdrawn from a groundwater basin over a long period of time (during which water supply conditions approximate average conditions) without developing an overdraft condition.

Permeability The capability of soil or other geologic formations to transmit water . See hydraulic conductivity.

Porosity The ratio of the voids or open spaces in alluvium and rocks to the total volume of the alluvium or rock mass.

Recharge Water added to an aquifer or the process of adding water to an aquifer. Groundwater recharge occurs either naturally as the net gain from precipitation, or artificially as the result of human influence.

Recharge basin A surface facility constructed to infiltrate surface water into a groundwater basin.

Safe yield The maximum quantity of water that can be continuously withdrawn from a groundwater basin without adverse effect.

Service area The geographic area served by a water agency.

Specific yield The ratio of the volume of water a rock or soil will yield by gravity drainage to the total volume of the rock or soil.

Stakeholder Any individual or organization that has an interest in water management activities. In the broadest sense, everyone is a stakeholder, because water sustains life. Water resources stakeholders are typically those involved in protecting, supplying, or using water for any purpose, including environmental uses, who have a vested interest in water-related decisions.

Sustainability Of, relating to, or being a method of using a resource so that the resource is not depleted or permanently damaged.

Transmissivity The product of hydraulic conductivity and aquifer thickness; a measure of the ability of water to move through the aquifer. Transmissivity generally has the units of ft^2/day or gallons per day/foot. Transmissivity is a measure of the subsurface's ability to transmit groundwater horizontally through its entire saturated thickness and affects the potential yield of wells.

Unconfined aquifer An aquifer which is not bounded on top by an aquitard. The upper surface of an unconfined aquifer is the water table.

Usable storage capacity The quantity of groundwater of acceptable quality that can be economically withdrawn from storage.

Water year A continuous 12-month period for which hydrologic records are compiled and summarized. Different agencies may use different calendar periods for their water years.

ATTACHMENT I

Interbasin Transfers.

Portions of the Report "**METHODOLOGY FOR ANALYSIS OF THE ENERGY INTENSITY OF CALIFORNIA'S WATER SYSTEMS, AND AN ASSSESSMENT OF MULTIPLE POTENTIAL BENEFITS THROUGH INTEGRATED WATER-ENERGY EFFICIENCY MEASURES*****", by Robert Wilkinson, Environmental Studies Program, University of California, Santa Barbara, 2000*.

ATTACHMENT I
INTERBASIN TRANSFERS

Note: ITRC notes that the report by Robert Wilkinson was well done, and that there was no need to repeat key findings from that report. Therefore, pertinent *portions* of that report are included verbatim in this attachment. If this attachment reads awkwardly, it is because ITRC has not included paragraphs and sections that ITRC deemed unrelated to the Agricultural Energy analysis that was the focus of the ITRC report for CEC.

METHODOLOGY FOR ANALYSIS OF THE ENERGY INTENSITY OF CALIFORNIA'S WATER SYSTEMS,

AND

AN ASSSESSMENT OF MULTIPLE POTENTIAL BENEFITS THROUGH INTEGRATED WATER-ENERGY EFFICIENCY MEASURES

EXPLORATORY RESEARCH PROJECT SUPPORTED BY:

ERNEST ORLANDO LAWRENCE BERKELEY LABORATORY,
CALIFORNIA INSTITUTE FOR ENERGY EFFICIENCY

Agreement No. 4910110

January 2000

Principle Investigator:

Robert Wilkinson
Environmental Studies Program
University of California, Santa Barbara *

* Contact:
(wilkinso@envst.ucsb.edu) phone: 805 569 2590, fax: 805 569 2718
1428 West Valerio Street, Santa Barbara, CA 93101

Interbasin Transfers

California's water systems are uniquely energy-intensive, relative to national averages, due to pumping requirements for major conveyance systems which move large volumes of water long distances and over thousands of feet in elevation lift. Some of the interbasin transfer systems (systems that move water from one watershed to another) are net energy producers, such as the San Francisco and Los Angeles aqueducts. Others, such as the State Water Project (SWP) and the Colorado River Aqueduct (CRA) require large amounts of electrical energy to convey water. On average, approximately 3,000 kWh is necessary to pump one acre-foot (AF) of SWP water to southern California,[i] and 2,000 kWh is required to pump one AF of water through the CRA to southern California.[ii]

As outlined in this study, energy inputs for local treatment and distribution, on-site uses (facility-level pumping, processing, thermal requirements for end-uses), and wastewater collection and treatment, must be added to the energy required to provide "raw" water supplies (from imports and/or local supplies) in order to develop an estimate for total embodied energy or energy intensity.

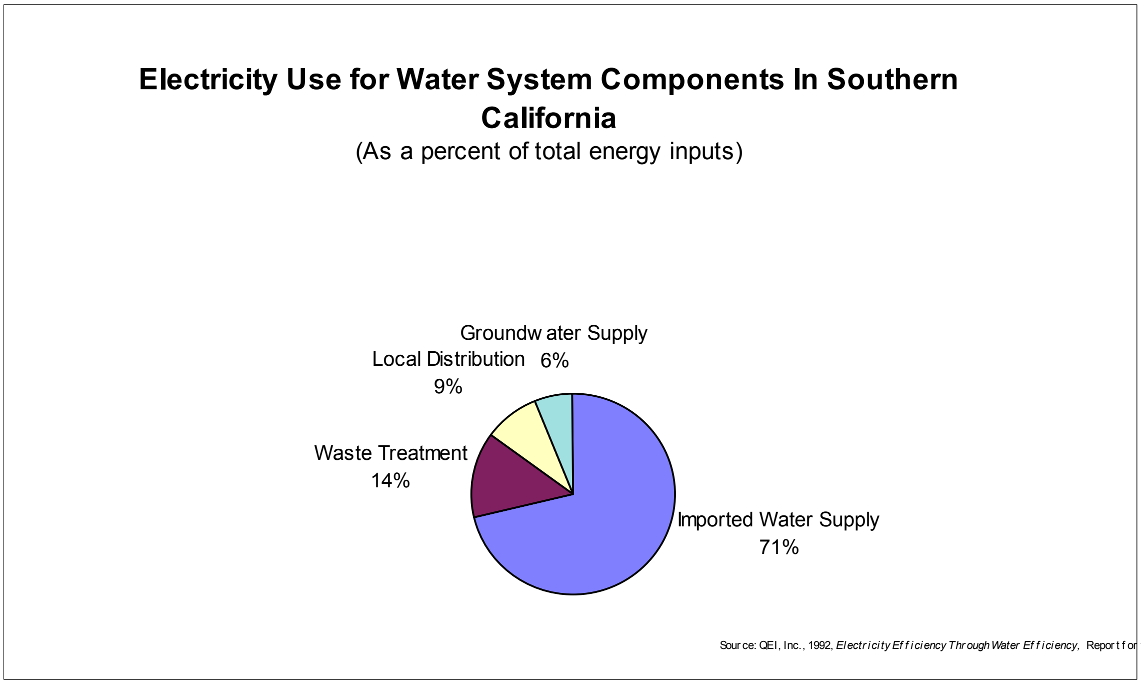
> ***Energy intensity***, or *embodied energy*, is the total amount of energy, calculated on a whole-system basis, required for the use of a given amount of water in a specific location.

Total energy requirements for use of marginal (e.g. imported) supplies of water in Southern California were estimated in 1992 in a study prepared for Southern California Edison at 3,519 kWh/acre-foot (0.01 kWh/gallon).[iii] This is an *average* figure for marginal supplies for the region. In specific geographic areas, the figure is *higher* due to additional pumping requirements. The average energy requirement for blended water (local and imported supplies) was estimated at 2,439 kWh/AF due to less energy intensive local supplies.

Water system operations provide a number of challenges for energy systems due to factors such as large loads for specific facilities, time and season of use, and geographic distribution of loads. Key pumping plants are among the largest electrical loads in the state. For example, the SWP's Edmonston Pumping Plant, situated at the foot of the Tehachapi mountains, raises water 1,926 feet (the highest single lift of any pumping plant in the world) and is one of the largest single users of electricity in the state.[iv] In total, the SWP is the largest single user of electricity in the state.[v]

Water use in homes located in some areas of the state accounts for the equivalent of a major end-use electrical appliance. For example, a study conducted for Southern California Edison found that the energy required to provide water use in a typical southern California residence can rank third behind the air conditioner and refrigerator as the largest energy-user "in" the home.[vi] (For homes with efficient refrigerators and without air conditioners, water use may be the *largest* energy user.) Approximately sixty percent of the state's population is located in Southern California.

The following graph indicates the average constituent energy inputs for water systems in southern California as a percent of total energy use for water systems.



Source: QEI, Inc., 1992, *Electricity Efficiency Through Water Efficiency*, Report for the Southern California Edison Company, p. 2.

California Energy Use

California uses more energy than most nations, with a total consumption of more than seven quads (quadrillion BTUs).[vii] On a per capita consumption basis, however, California ranks 48th in the nation,[viii] and on the basis of energy used per dollar of gross product, California ranks 46th.[ix]

According to the California Energy Commission, California's electricity use has increased an average of 2.3 percent per year since 1977. The greatest share of electricity consumption is in the commercial sector, using 34 percent of the total and growing at an average annual rate of 3.3 percent. Residential electricity consumption has increased 2.3 percent per year on average, and industrial demand has grown at 1.4 percent per year.[x] By some projections, the state's population could increase 50 percent by 2020,[xi] and energy requirements will continue to rise with it.

The Metropolitan Water District of Southern California (MWD) reached similar findings. MWD estimates that energy requirements to deliver water to residential customers equals as much as 33 percent of the total average household electric use.[xii] A recent study for the Electric Power Research Institute (EPRI) by Franklin Burton indicates that at a national level, water systems account for an estimated 75 billion kWh (3% of total electricity demand).[xiii] Due to California's settlement patterns, topography, and climate patterns, energy use for water systems is greater than in other areas. Water systems in California are estimated to use about 6.9% of the state's electricity.

Water Sources and Use in California

The distribution, in both time and space, of water sources in California impact the energy requirements of water systems. A brief review of the context for water systems is provided here.

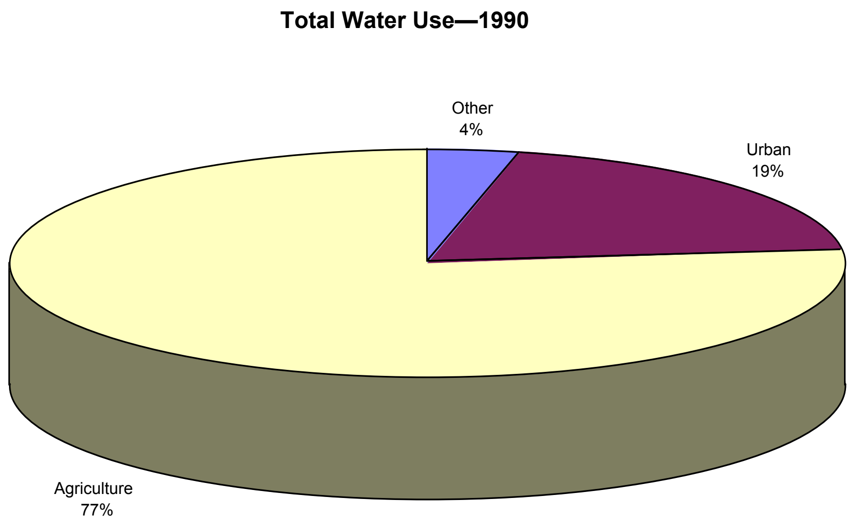
Three principle sources provide the state with water: (1) surface water**, which is often diverted or extracted and stored in reservoirs; (2)** groundwater**; and (3)** imported supplies**, principally from the Colorado River.[xiv] On average, about 200 million acre feet per year (mafy) falls as precipitation, two-thirds of which falls in the northern one-third of the state.[xv] About 71 mafy is surface runoff, stored and redistributed for human use.[xvi] Water from the Colorado River Basin supplements in-state supplies and provides for about 14 percent of the state's total water; it provides more than 60 percent of the 8.4 million acre-feet used in southern California.[xvii] Groundwater supplies an average of about 7 mafy, but in drought years, this may increase drastically. Overdraft and contamination has reduced the availability of groundwater supplies throughout the state, and salt-water intrusion in coastal aquifers is already a problem in some coastal areas.**

California Average Annual Water Supply and Extractions From All Sources

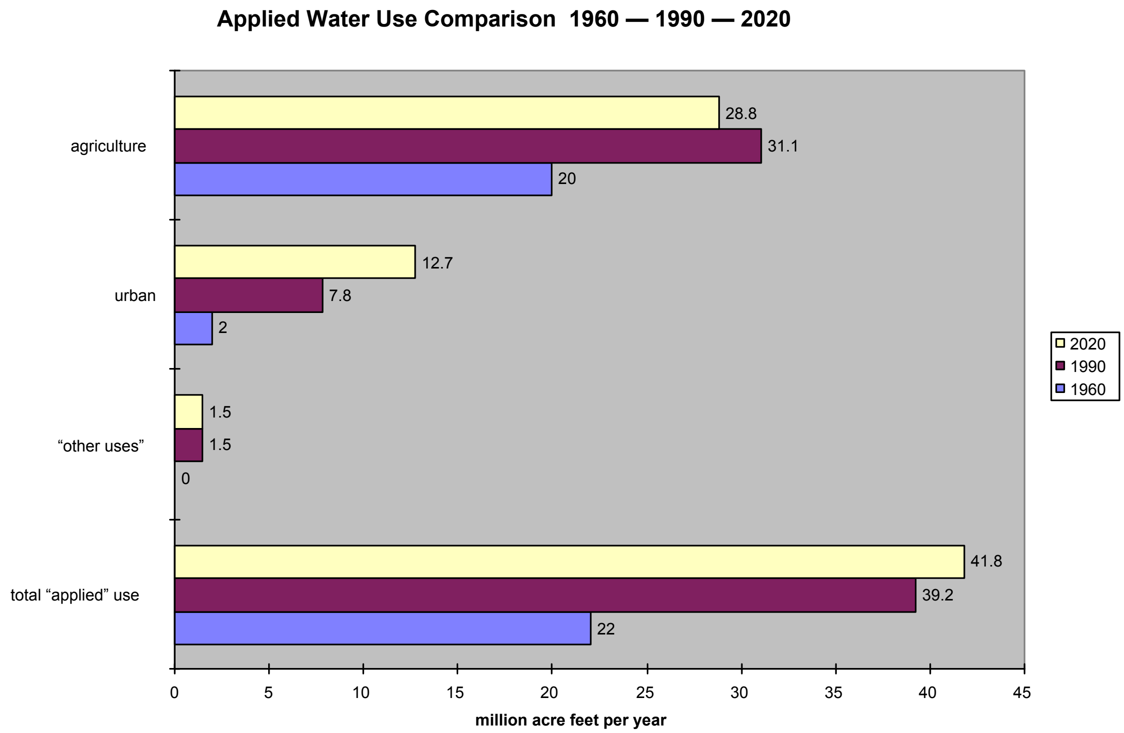
Water Source	**Million Acre Feet per Year (mafy)**	
Precipitation	193.0	
Natural recharge, percolation, and non-developed uses (a)	122.0	
surface runoff (historical range: 15 mafy [1977] to 135 mafy [1983])	70.8	
Average annual water supply (b)	85.0	
Total groundwater resources	850.0	
Economically recoverable groundwater resources	250.0	
Extractions of surface water (c)	21.6	
Extractions of groundwater	15.0	
"Use" of groundwater (does *not* include overdraft)	7.1	Overdraft
(d) 1.3		
"Net" use of groundwater ("use" plus overdraft)	8.4	
Surface storage capacity (reservoirs) (e)	42.8	
Delta extractions (f)	10.3	
Reclaimed water	0.2	
Desalination	0.017	
Imported Water		
Colorado River imports (g)	5.2	
"Local imports"	1.0	

Sources: California Department of Water Resources. *California Water Plan Update*, Bulletin 160-93. 1994. California Legislative Analyst's Office. Colorado River Water: Challenges for California." October 16, 1997. (http://www.lao.ca.gov/101697_colorado_river.html)
(a): "Non-developed" uses are evaporation, evapotranspiration from native plants, and percolation/
(b): Appears to include groundwater extractions including overdraft of 15 mafy and surface at 70 mafy.
(c): Based on sum of local, SWP, CVP, and other federal projects.
(d): DWR projects no overdraft from 2000 forward (Vol. 1, p. 6, Table 1-2), although it states on the same page that "...the reductions in overdraft seen in the last decade in the San Joaquin Valley will *reverse as more ground water is pumped* to make up for reductions in surface supplies from the Delta." (emphasis added)
(e): California Department of Water Resources, Division of Dams. "Dams Statistical File," July 1997.
(f): Based on figures for SWP and CVP.
(g): California's entitlement is 4.4 mafy

The water diversion, conveyance, and storage systems developed in California in this century, such as the Central Valley and State Water Projects, the Colorado and Los Angeles Aqueducts, are remarkable engineering accomplishments. These water works move millions of acre-feet of water around the state annually. The state's 1,200-plus reservoirs have a total storage capacity of 42 million acre feet (maf).[xviii]



Water in California is extracted from natural systems primarily for use in the urban and agricultural sectors. The urban water use sector includes residential, commercial, industrial, and institutional uses, as well as municipal uses such landscaping and fire-fighting. As the state's population continues to grow, urban uses of water are steadily increasing. Agricultural demand, however, peaked at the end of the 1980s and is declining.[xix] In the early 1970s, agriculture used about 85 percent of the state's developed water supply.[xx] By the end of the 1980s, the percentage of the state's water used by agriculture had fallen to 80 percent. Irrigated land area increased from about 4 million acres in 1930 to a high in 1981 of 9.7 million acres.[xxi] In place of the continuing increase in water used for irrigation projected in earlier forecasts, the state now projects a continued decline in water use for agriculture.[xxii] Land retirement, crop shifting, water transfers, and improved efficiencies in irrigation as well as conveyance and management will all contribute to a reduction in water used for irrigation.[xxiii] Despite this decline, however, total extractions from the state's water systems has increased through the years, with flows for the environment decreasing as a result.



* Total of "other outflow" and "environmental", a category which is not disaggregated for 1960. Assumes total water resources of 85 mafy for 2020, consistent with 1960 and 1990 data.

Source: California Department of Water Resources. *California Water Plan Update*, Bulletin 160-93. 1994.

With very real limits to the state's water system, and every major supply source being reduced, the state's water systems may be fairly said to be stressed. Every major water supply source in California is currently beyond the physical or legal capacity to be sustained. California's entitlement to Colorado River water is 4.4 mafy, but it has been taking 5.2 mafy.[xxiv] An average of 1.3 mafy of groundwater extraction is overdraft [xxv] (extractions exceed recharge by more than 18 percent). In severe drought years, this overdraft may be as high as four to 10 mafy,[xxvi] which drastically depletes economically recoverable groundwater resources.

Data for Specific Geographic Locations

The energy intensity of water is usually determined by geographic factors including the location of the sources of water and the location of end-use. Water in California is often moved from one area to another via conveyance facilities. Total energy requirements for the conveyance of water in systems like the SWP and the CRA to particular destinations may be estimated with reasonable accuracy.[xxvii] In a given geographic area, the water used may be a mix of imported and/or local supplies from surface or groundwater sources. [xxviii] Each of these sources can be identified and an energy value per unit of water from each may be determined.

Water is typically treated and delivered by a local water management entity, and the wastewater generated by users is usually collected and treated in specific geographic areas.[xxix] Each responsible entity, from imported supply delivery agencies to local treatment and distribution, to wastewater authorities, operate within specific geographic areas. In many cases the boundaries for jurisdiction of these agencies overlap or are inconsistent. The analysis must therefore account for geographic boundaries and attribute the appropriate energy factor for each element of the system. The use of geographic information systems (GIS) to delineate the boundaries and record energy and other data is envisioned as a next step in the research initiated here. One significant benefit of the use of GIS is the ability to define areas of use based on location, and to attribute the energy per unit of water values accordingly.

Methodology for Analysis

One objective of this exploratory research project is the development of a methodology for the calculation of total embodied energy in water in a particular location or geographic area of use. To meet this objective, a spread-sheet tool has been developed with equations embedded to calculate total energy requirements for water use. Both the equations and the data input to the spread-sheet are fully transparent, so the user can alter elements as needed. The spread-sheet can be linked directly to GIS applications, such that data can be calculated and displayed for the user through the GIS tool.

For purposes of this exploratory project, all data listed in the spread-sheet is referenced to the text (located in the notes section of the appendix) which explains the source of the data and other information.

Energy and Water Units

The units for energy are kilowatt hours (kWh) and therms. Therms (based on the energy content of fuel) are 100,000 British thermal units (BTUs). For comparison of total energy, therms are converted to kWh equivalent.

The common unit for water supply is an "acre-foot" (AF). An acre-foot of water is the volume of water that would cover one acre with one foot. An acre-foot equals 325,851 gallons, or 43,560 cubic feet, or 1,233.65 cubic meters. (See conversion table in the Appendix.) Wastewater is typically measured in "million gallons per day" (MGD). Figures have been converted to AF to provide consistency. One MGD equals 1,120 AF per year, and one AFY equals 0.000893 MGD. One acre-foot equals 0.325851 MG.

Energy Inputs Included (and Excluded) in the Analysis

The methodology developed for this analysis seeks to account for all of the energy inputs embodied in water delivered to and used in specific locations. Energy inputs for extractions from natural systems through end-uses to ultimate disposal or re-use are included.

For purposes of this analysis, power generated by water systems separate from the delivery and conveyance systems is not included in the calculations. This is because power would be generated in any event, regardless of the ultimate use of the water, and whether power is generated or not does not influence the energy requirements for delivery and use. For example, hydro-power generation from water flowing from northern California to the Delta is not counted in this analysis because it would be generated whether the water flows out the Golden Gate or is pumped out of the delta to southern California in the SWP. The calculations for the SWP therefore start at the delta. (This methodology is not intended to diminish the role and importance of hydro-power production. The consideration is strictly the correct methodology for assessment of the total embodied energy in each unit of water used in a specific location.)

Power generated as part of the conveyance systems, however, is counted because it is directly related to the volumes of water pumped through the system. (For example, power recovered from the Warne and Castaic plants on the west branch of the SWP recover a portion of the energy inputs in the system from the Banks through Wind Gap pumping plants in the Central Valley and the Edmonston and Oso pumping plants that lift water over the Tehachapi Mountains. Total energy requirements are adjusted to credit back to the system the power generation against the pumping requirements to a given point in the system.

Policy Implications

This exploratory research project addresses the linkage between efficiency improvements in water and energy use in California and the potential multiple benefits to be derived from them. Efficient water and energy use, and the facilitation of cost-effective measures to improve efficiency for both, is an important policy challenge and opportunity. Multiple benefits from integrated strategies constitute potential opportunities for policy development.

With better information regarding the energy implications of water use, public policy and combined investment and management strategies between energy, water, and wastewater agencies and utilities can be improved. Potential benefits include improved allocation of capital, avoided capital and operating costs, reduced burdens on rate-payers, and environmental benefits. Other societal goals, including restoration and maintenance of environmental quality, can also be addressed more cost-effectively through policy coordination. Full benefits derived through water/energy efficiency strategies have not been adequately quantified or factored into policy, although the California Public Utilities Commission adopted principles supporting such approaches in 1989.[xxx] Recent drought cycles in California, coupled with economic considerations and an increasing concern for environmental impacts, have confirmed the importance of efficient resource use as a policy objective. Energy efficiency benefits accruing as a result of water efficiency programs hold significant potential.

Overview of Energy Inputs to Water Systems

There are four principle energy elements in water systems:

primary water extraction and supply delivery (imported and local)
treatment and distribution within service areas
on-site water pumping, treatment, and thermal inputs (heating and cooling)
wastewater collection and treatment

Pumping water in each of these four stages is energy-intensive and constitutes a major use of California's total energy. Other important components of energy embodied in water use include groundwater pumping, treatment and pressurization of the water supply systems, treatment and thermal energy (heating and cooling) applications at the point of end-use, and wastewater pumping and treatment.

1. ***Primary water extraction and supply delivery***
   Moving water from near sea-level in the Sacramento-San Joaquin delta to the San Joaquin-Tulare Lake Basin, the Central Coast, and Southern California, and from the Colorado River to metropolitan Southern California, is highly energy intensive. As noted, approximately 3,000 kWh is necessary to pump one acre-foot (AF) of SWP water to southern California, and 2,000 kWh is required to pump one AF of water through the CRA to southern California.[xxxi] Groundwater pumping also requires significant amounts of energy depending on the depth of the source. (Data on groundwater is incomplete and difficult to obtain because California does not manage groundwater resources, other than in adjudicated basins, and meters and data reporting are not required.)

2. ***Treatment and distribution within service areas***
   Within local service areas, water is treated, pumped, and pressurized for distribution. Local conditions and sources determine both the treatment requirements and the energy required for pumping and pressurization.

3. ***On-site water pumping, treatment, and thermal inputs***
   Individual water users use energy to further treat water supplies (e.g. softeners, filters, etc.), circulate and pressurize water supplies (e.g. building circulation pumps), and heat and cool water for various purposes.

4. ***Wastewater collection and treatment***
   Finally, wastewater is collected and treated by a wastewater authority (unless a septic system or other alternative is being used). Wastewater is sometimes pumped to treatment facilities where gravity flow is not possible, and the standard treatment processes require energy for pumping, aeration, and other processes. (In cases where water is reclaimed and re-used, the calculation of total energy intensity is adjusted to account for wastewater as a *source* of water supply. The energy intensity generally includes the additional energy for treatment processes beyond the level required for wastewater discharge, plus distribution.)

Water pumping, and specifically the long-distance transport of water in conveyance systems, is a major element of California's total demand for electricity. Water use, based on embodied energy, is the second or third largest consumer of electricity in a typical Southern California home after refrigerators and air conditioners. Electricity required to support water service in the typical home in Southern California is estimated at between 14% to 19% of total residential energy demand. If air conditioning is not a factor the figure is even higher.[xxxii] Nearly three quarters of this energy demand is for pumping imported water.

Both California State Water Project (SWP) and Colorado River supplies are energy-intensive due to pumping requirements. The SWP supplies average 2,956 kWh/acre foot for delivery pumping alone, with Colorado River supplies averaging 1,916 kWh/acre foot.[xxxiii] For the 1989-90 fiscal year, Colorado river pumping[xxxiv] (without accounting for station service and transmission losses) was 2,434,567,313 kWh.[xxxv] The SWP required approximately 3,420,092,000 kWh in the same year.[xxxvi] The cost of this electricity is incorporated into water rates.

Primary Users: M&I and Agricultural

The two major water users in California are agriculture (at around 80% of the total extracted amounts) and urban or "M&I" (municipal and industrial) sector at around 20%. The present analysis is focused on the M&I sector for several reasons. First, important data for the agriculture sector analysis is unavailable or difficult to obtain due to prevailing groundwater law and other factors. Second, water use in the M&I sector is considerably more energy-intensive than in agriculture due in large part to major inter-basin conveyance systems.

Water managers typically identify urban water use in a broad category called *municipal and industrial* (M&I), which generally includes residential uses as well as commercial and institutional, industrial, and municipal uses. An important sub-set of M&I water use is the non-residential category of *commercial, industrial, and institutional* (CII) users.[xxxvii]

As noted above, this analysis focuses on the M&I sector due to its energy intensity and the availability of data.

Major Supply Systems: Interbasin Transfers

Major inter-basin water transfers in California began at the turn of the 20th century. Early transfers, such as the Colorado River diversions to the Imperial Valley, were gravity fed and therefore required no energy for pumping. The infamous Los Angeles aqueduct and San Francisco's water from Hetch Hetchy Valley (in Yosemite National Park) are *net energy producers* due to the hydro-power production of the systems. Systems built later in the century, however, required significant pumping plants ad energy inputs to run them to lift water over mountain ranges. The State Water Project and the Colorado River Aqueduct are the two most energy-intensive systems in the state, and are therefore the focus of this analysis.

The State Water Project

The State Water Project (SWP) is managed by the California Department of Water Resources (DWR) and provides water for agricultural and urban uses.[xxxviii] SWP facilities include 28 dams and reservoirs, 22 pumping and generating plants, and nearly 660 miles of aqueducts.[xxxix]

The SWP stores water in the Feather River watershed in Northern California. Lake Oroville, the project's largest storage facility, has a capacity of about 3.5 million acre-feet. Three smaller upstream reservoirs provide additional storage.[xl] (Oroville Dam is the tallest and one of the largest earth-fill dams in the United States.)[xli] Power is generated at the Oroville Dam as water is released down the Feather

River, which flows in natural water courses into the Sacramento River, through the Sacramento-San Joaquin Delta, and to the ocean through the San Francisco Bay.

Water is pumped out of the delta for the SWP at two locations. From the northern Delta, Barker Slough Pumping Plant diverts water for delivery to Napa and Solano counties through the North Bay Aqueduct.[xlii] Further south at the Clifton Court Forebay, water is pumped into Bethany Reservoir by the Banks Pumping Plant. From Bethany Reservoir, the majority of the water is conveyed south in the 444-mile-long Governor Edmund G. Brown California Aqueduct to agricultural users in the San Joaquin Valley and to urban users in Southern California. The South Bay Pumping Plant also lifts water from the Bethany Reservoir into the South Bay Aqueduct.[xliii]

State Water Project
Names and Locations of Primary Water Delivery Facilities

DWR provides the following description of water conveyance in the SWP:

California State Water Project

The California Aqueduct moves water south along the west side of the San Joaquin Valley. It transports water to the Gianelli Pumping-Generating Plant and the San Luis Reservoir[xliv] which has a storage capacity of more than 2 million acre-feet.[xlv] SWP water not stored in San Luis Reservoir, and water released from San Luis, continues to flow south through the San Luis Canal, a portion of the California Aqueduct jointly owned by the Department and the USBR. As the water flows through the San Joaquin Valley, it is raised over 1,000 feet by four pumping plants—Dos Amigos, Buena Vista, Teerink, and Chrisman — before reaching the foot of the Tehachapi Mountains. In the San Joaquin Valley near Kettleman City, the Coastal Branch Aqueduct extends west to serve municipal and industrial water users in San Luis Obispo and Santa Barbara counties.

The remaining water conveyed by the California Aqueduct is delivered to Southern California. Pumps at Edmonston Pumping Plant, situated at the foot of the mountains, raise the water 1,926 feet — the highest single lift of any pumping plant in the world. Then the water enters 8.5 miles of tunnels and siphons as it flows into the Antelope Valley, where the California Aqueduct divides into two branches, the East Branch and the West Branch. The East Branch carries water through the Antelope Valley into Silverwood Lake in the San Bernardino Mountains. From Silverwood Lake, the water flows through the San Bernardino Tunnel into the Devil Canyon Powerplant. The water continues down the East Branch to Lake Perris, the southernmost SWP reservoir. Water in the West Branch flows through the Warne Powerplant into Pyramid Lake in Los Angeles County. From there it flows through the Angeles Tunnel and Castaic Powerplant into Castaic Lake, terminus of the West Branch.

California Department of Water Resources, 1996, *Management of the California State Water Project*. Bulletin 132-96.

The SWP is the largest consumer of electrical energy in the state, requiring an average of 5,000 GWh per year.[xlvi] The energy required to operate the SWP is provided by a combination of DWR's own hydroelectric and coal-fired generation plants and power purchased from other utilities. The project's eight hydroelectric power plants, including three pumping-generating plants, and a coal-fired plant produce enough electricity in a normal year to supply about two-thirds of the project's necessary power.

Energy requirements would be considerably higher if the SWP was delivering full entitlement volumes of water. The project has in fact been delivering approximately half its contracted volumes. As DRW comments:

> Facilities were designed and built to meet demands for water through 1990; these demands were projected to be about 4.0 million acre-feet. Actual demand, however, has not developed as projected, owing to circumstances such as slower population growth, changes in local use, local water conservation programs, and conjunctive use programs. The most SWP entitlement water delivered to date was about 2.8 million acre-feet in 1989.[xlvii]

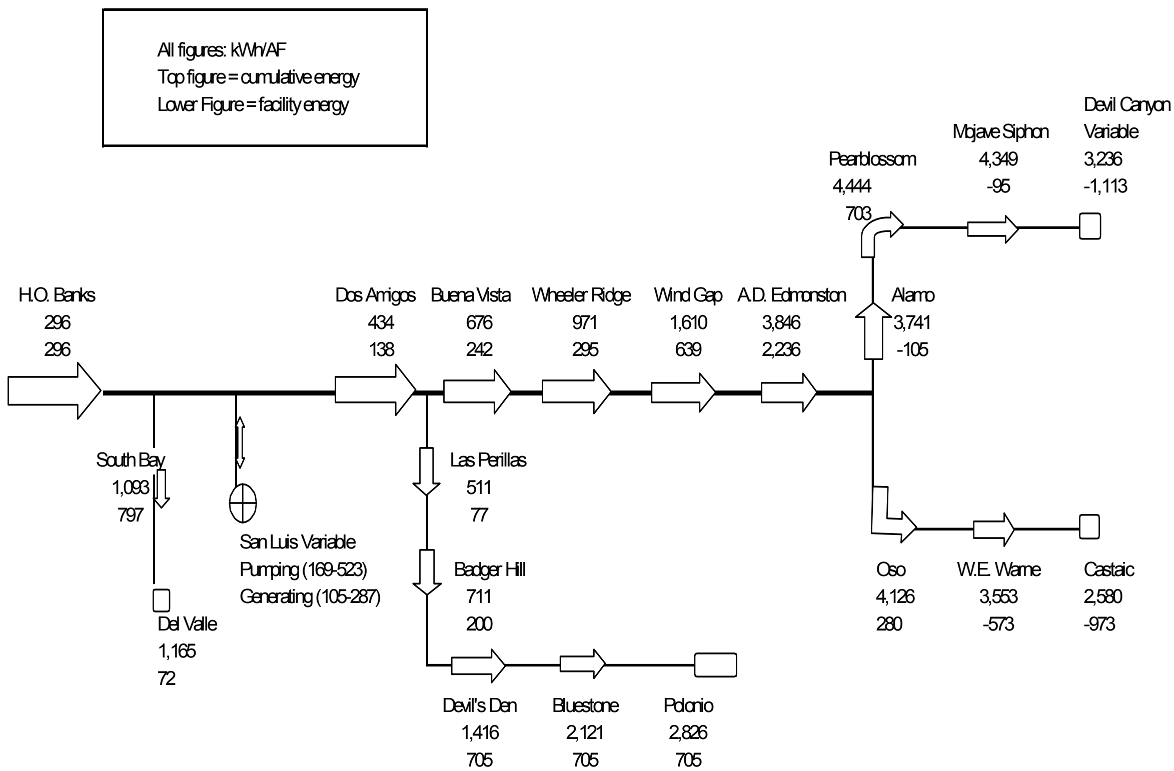
MWD provides the following information on SWP energy requirements:

> The electric power required to pump SWP water is primarily off-peak energy with a substantial portion supplied by Edison under a 1979 Power Contract and 1981 Capacity Exchange Agreement. On-peak energy is provided by SWP power generation facilities located throughout the state. DWR has long-term transmission contracts with PG&E and Edison for delivery of power from SWP generation facilities to SWP pumping plants.
>
> Metropolitan pays approximately 60-80 percent of the total power costs incurred by DWR for the SWP depending upon delivery, since it is the largest and one of the last contractors on the aqueduct, and its water is pumped the furthest. Approximately 3,000 kWh (net) are required to pump one acre-foot of water to the Los Angeles basin from the Sacramento-San Joaquin Delta. Metropolitan's SWP deliveries require approximately 2,700 GWh of energy annually.[xlviii]

State Water Project
Names, Locations and Generating Capacity of Primary Power Facilities

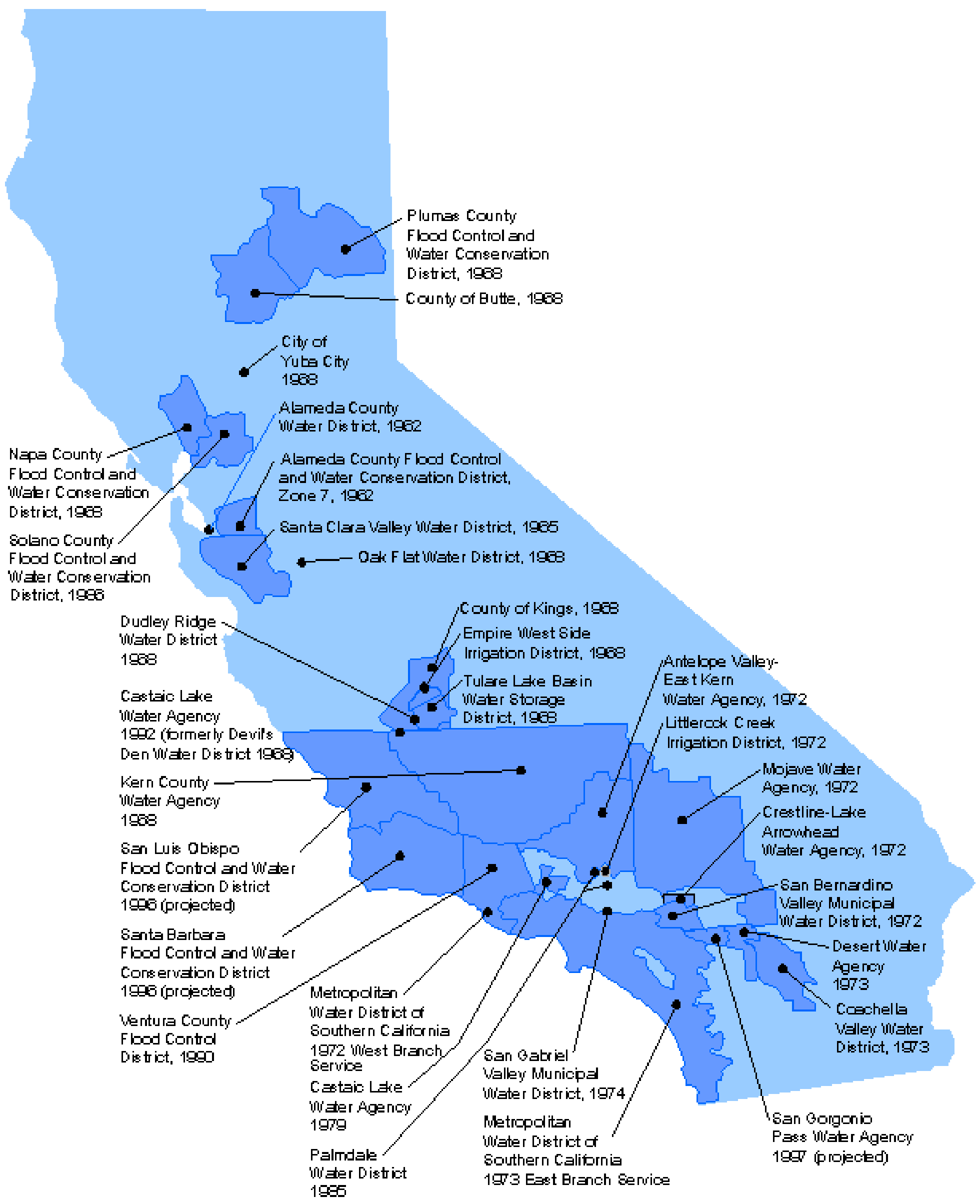
The following chart shows energy requirements to pump an acre-foot of water through each pumping station on the SWP. Also shown is the cumulative kilowatt-hours necessary to pump the water as it moves south down the state and the recovery energy from generators on the down-hill runs.

State Water Project
Kilowatt-Hours Per Acre Foot Pumped
(Includes Transmission Losses)



Source: Based on data from: California Department of Water Resources, State Water Project Analysis Office, Division of Operations and Maintenance, *Bulletin 132-97*, 4/25/97.

State Water Project
Water Delivered in Calendar Year 1995 and Delivery Locations



State Water Project
Water Deliveries by Section

Colorado River Aqueduct

Significant volumes of water are imported to Southern California from the Colorado River via the Colorado River Aqueduct (CRA). Though MWD's entitlement to Colorado River water is 550,000 afy, it has extracted as much as 1.3 mafy through waste reduction arrangements with IID (adding about 106,000 afy) and by using "surplus" water.[xlix] The Colorado River water supplies require about 2,000 kWh/af for conveyance to Lake Mathews in the Los Angeles basin.

The Colorado River Aqueduct extends 242 miles from Lake Havasu on the Colorado River to its terminal reservoir, Lake Mathews, near Riverside. The Colorado River aqueduct was completed in 1941 and expanded in 1961 to a capacity of more than 1 MAF per year. Five pumping plants lift the water 1,616 feet, over several mountain ranges, to southern California. To pump an average of 1.2 million acre-feet of water per year into the Los Angeles basin requires approximately 2,400 GWh of energy for the CRA's five pumping plants.[l] On average, the energy required to import Colorado River water is therefore about 2,000 kWh/AF. The aqueduct was designed to carry a flow of 1,605 cfs (with the capacity for an additional 15%).

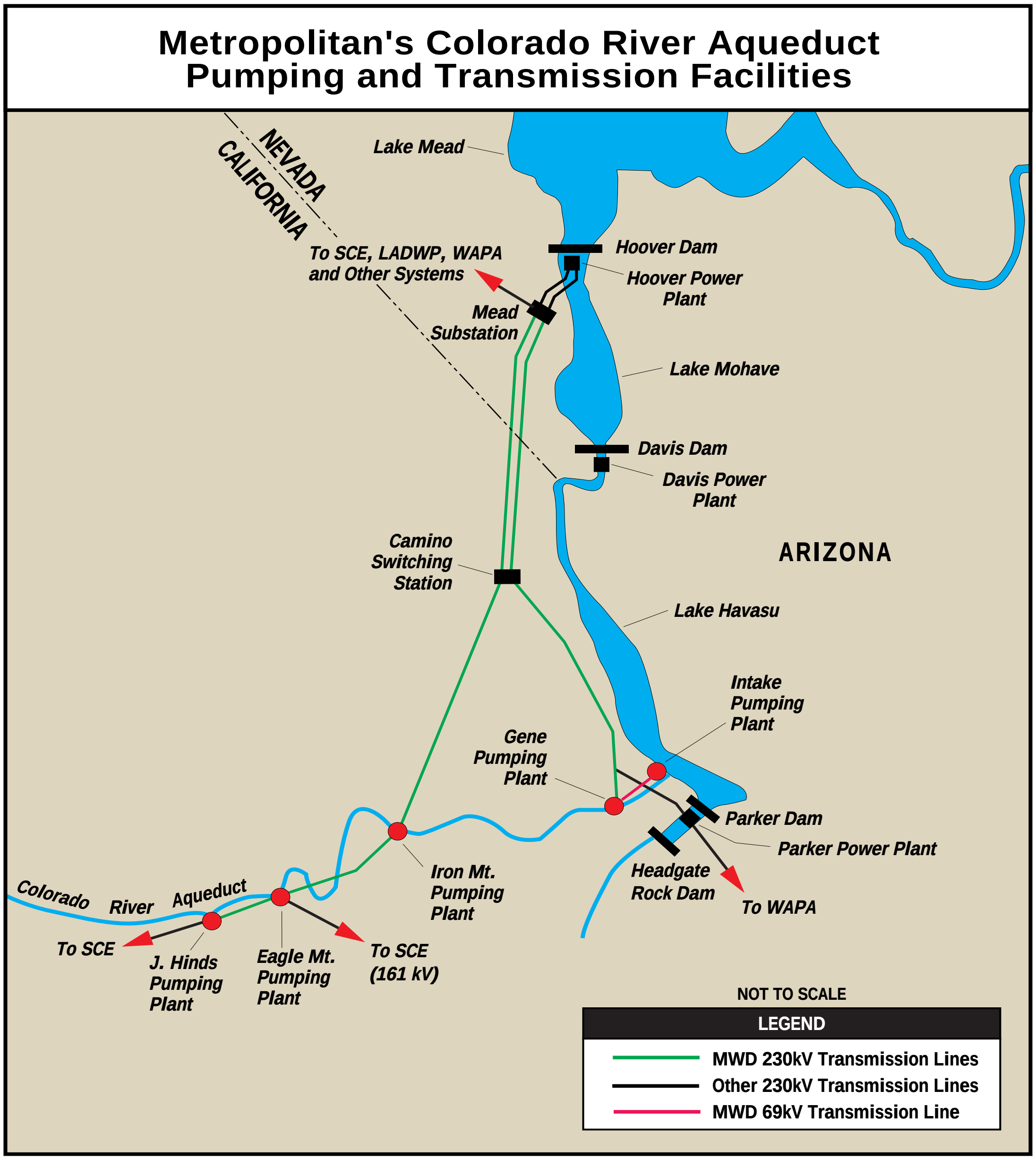
The sequence for pumping the water supplies is as follows: The Whitsett Pumping Plant elevates water from Lake Havasu 291 feet out of the Colorado River basin. At "mile 2," Gene pumping plant elevates water 303 feet to Iron Mountain pumping plant at mile 69, which then boosts the water another 144 feet. The last two pumping plants provide the highest lifts - Eagle Mountain, at mile 110, lifts the water 438 feet, and Hinds Pumping Plant, located at mile 126, lifts the water 441 feet. [li] The five pumping plants each have nine pumps. The plants are designed for a maximum flow of 225 cubic feet per second (cfs). The CRA is designed to operate at full capacity with eight pumps in operation at each plant (1800 cfs). The ninth pump operates as a spare to facilitating maintenance, emergency operations, and repairs.[lii]

MWD has recently improved the system's energy efficiency. The average energy requirement for the CRA was reduced from approximately 2,100 kWh /af to about 2,000 kWh /af "through the increase in unit efficiencies provided through an energy efficiency program."[liii] The energy required to pump each af of water through the CRA is essentially constant, regardless of the total annual volume of water pumped. This is due to the 8-pump design at each pumping plant. The average pumping energy efficiency does not vary with the number of pumps operated, and the same 2,000 kWh /af estimate is appropriate for both the "Maximum Delivery Case" and the "Minimum Delivery Case."[liv]

Based on the relatively steep grade of the CRA, limited active water storage, and transit times between plants, the system does not generally lend itself to shifting pumping loads from on-peak to off-peak. Under the Minimum Delivery Case, the reduced annual water deliveries would not necessarily bring a reduction in annual peak load, since an 8-pump flow may still need to be maintained in certain months.[lv]

Electricity to run the CRA pumps is provided by power from hydroelectric projects on the Colorado River as well as off-peak power purchased from a number of utilities. The Metropolitan Water District has contractual hydroelectric rights on the Colorado River to "more than 20 percent of the firm energy and contingent capacity of the Hoover power plant and 50 percent of the energy and capacity of the Parker power plant."[lvi] Energy purchased from utilities makes up approximately 25 percent of the remaining energy needed to power the Colorado River Aqueduct.[lvii]

Colorado River Aqueduct
Pumping and Power Transmission Facilities



SOURCES

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[i] An acre-foot of water is the volume of water that would cover one acre to a depth of one foot. An acre-foot equals 325,851 gallons, or 43,560 cubic feet, or 1233.65 cubic meters. (See conversion table in the Appendix.)

[ii] Metropolitan Water District of Southern California, *Integrated Resource Plan for Metropolitan's Colorado River Aqueduct Power Operations*, 1996, p.5.

[iii] QEI, Inc., 1992, *Electricity Efficiency Through Water Efficiency*, Report for the Southern California Edison Company, p. 2.

[iv] California Department of Water Resources, 1996, *Management of the California State Water Project*. Bulletin 132-96.

[v] Carrie Anderson, 1999, "Energy Use in the Supply, Use and Disposal of Water in California", Process Energy Group, Energy Efficiency Division, California Energy Commission, p.1.

[vi] Third largest user of power in southern California residences based on a study for Southern California Edison by QEI, Inc., 1992, *Electricity Efficiency Through Water Efficiency*, Report for the Southern California Edison Company, pp. 23-24.

[vii] California Energy Commission, http://www.energy.ca.gov/reports/stats/table58.html (March 4, 1998)

[viii] California Department of Finance. California Statistical Abstract. Table P-2 "Resident Population July 1, 1996," and Table P-23 "Per Capita Energy Consumption, 1994." December 17, 1997. (http://www.dof.ca.gov/html/fs_data/stat-abs/toc.htm)

[ix] California Energy Commission, http://www.energy.ca.gov/reports/stats/table58.html (March 4, 1998).

[x] California Energy Commission, http://www.energy.ca.gov/reports/stats/table41.html (March 4, 1998).

[xi] Willis, Doug. "'Serious' water need predicted by 2020." Associated Press. *Santa Barbara News-Press*. January 31, 1998.

[xii] Metropolitan Water District of Southern California, 1999, Fact Sheet on Electric Industry Restructuring, 2/99 p. 2.

[xiii] Burton, Franklin L., 1996, *Water and Wastewater Industries: Characteristics and Energy Management Opportunities*. (Burton Engineering) Los Altos, CA, Report CR-106941, Electric Power Research Institute Report, p.ES-1.

[xiv] Conjunctive use of surface and groundwater, re-use of agricultural and urban water, inflow from Oregon, and other factors make precise accounting for water supplies a complicated task.

[xv] Kahrl, William L., et al. *The California Water Atlas*. California Department of Water Resources, 1979. p. 3.

[xvi] California Department of Water Resources, 1994, *California Water Plan Update,* Bulletin 160-93.

[xvii] California Legislative Analyst's Office. "Colorado River Water: Challenges for California." December 16, 1997. (http://www.lao.ca.gov/101697_colorado_river.html)

[xviii] California Department of Finance. California Statistical Abstract. Table G-3 "Major Dams and Reservoirs of California." December 17, 1997. (http://www.dof.ca.gov/html/fs_data/stat-abs/toc.htm)

[xix] California Department of Water Resources, November 1987, *California Water: Looking to the Future*, Bulletin 160-87 p.9; California Department of Water Resources, 1994, *California Water Plan Update,* Bulletin 160-93.

[xx] California Department of Water Resources, Bulletin 160-74, 1974, p.2.

[xxi] California Department of Water Resources, November 1987, *California Water: Looking to the Future*, Bulletin 160-87 p.9.

[xxii] California Department of Water Resources, 1994, *California Water Plan Update,* Bulletin 160-93, Vol. 1, pp. 159-184. Projection for 2020 on p.181, Table 7-13. (See Figure 7-1 on page 159 for a comparison of Bulletin 160 projections.)

[xxiii] DWR includes extensive discussion of the changes in the agricultural sector and in its water use in Bulletin 160-93.

[xxiv] California Legislative Analyst's Office. "Colorado River Water: Challenges for California." December 16, 1997.

(http://www.lao.ca.gov/101697_colorado_river.html)

[xxv] California Department of Water Resources, 1994, *California Water Plan Update,* Bulletin 160-93.

[xxvi] Kahrl, William L., et al. *The California Water Atlas*. California Department of Water Resources, 1979. p. 3.

[xxvii] See pumping diagram of the SWP pumping system with cumulative pumping energy expressed in kWh/AF by location on the system and related maps.

[xxviii]For example, a specific basin in an urban area may use 65% imported state water, 25% Colorado River water, and 10% ground water. Sewage is treated for the basin at a specific treatment plant. The energy embodied in interior and exterior (no sewage) water use, plus thermal energy for water heating and cooling, may be estimated. Impacts of efficiency improvements may then be determined based on marginal benefits including energy impacts. (See Figure 1 attached.)

[xxix] In some cases wastewater is directed to septic systems.

[xxx]CPUC Decision No. 89-12-057, December 20, 1989.

[xxxi] Metropolitan Water District of Southern California, *Integrated Resource Plan for Metropolitan's Colorado River Aqueduct Power Operations*, 1996, p.5.

[xxxii]QEI, Inc., 1992, *Electricity Efficiency Through Water Efficiency*, Report for the Southern California Edison Company, p. 24.

[xxxiii]Figures cited are *net* energy requirements (gross energy for pumping minus energy recovered through generation).

[xxxiv]The Colorado River water is lifted over 1,617 feet to move it over several mountain ranges.

[xxxv]QEI, Inc., 1992, *Electricity Efficiency Through Water Efficiency*, Report for the Southern California Edison Company, p. 7.

[xxxvi]The SWP is pumped from near sea-level in the delta to Southern California over the Tehachapi Mountains. Further pumping is required to bring the water to the furthest reaches of the system.

[xxxvii] Wilkinson, Robert C., Arlene Wong, and Lisa Owens-Viani, 1999, "An Overview of Water-Efficiency Potential in the CII Sector"; *Sustainable Use of Water: California Success Stories*, Lisa Owens-Viani, Arlene Wong, and Peter Gleick, Eds., Pacific Institute, January 1999.

[xxxviii] "The SWP, managed by the Department of Water Resources, is the largest state-built, multi-purpose water project in the country. Approximately 19 million of California's 32 million residents receive at least part of their water from the SWP. SWP water irrigates approximately 600,000 acres of farmland. The SWP was designed and built to deliver water, control floods, generate power, provide recreational opportunities, and enhance habitats for fish and wildlife." California Department of Water Resources, *Management of the California State Water Project*. Bulletin 132-96. p.xix.

[xxxix] California Department of Water Resources, 1996, *Management of the California State Water Project*. Bulletin 132-96.p.xix.

[xl] Three small reservoirs upstream of Lake Oroville — Lake Davis, Frenchman Lake, and Antelope Lake — are also SWP facilities. California Department of Water Resources, 1996, *Management of the California State Water Project*. Bulletin 132-96.

[xli] California Department of Water Resources, 1996, *Management of the California State Water Project*. Bulletin 132-96.

[xlii] The North Bay Aqueduct was completed in 1988. (California Department of Water Resources, 1996, *Management of the California State Water Project*. Bulletin 132-96.)

[xliii] The South Bay Aqueduct provided initial deliveries for Alameda and Santa Clara counties in 1962 and has been fully operational since 1965. (California Department of Water Resources, 1996, *Management of the California State Water Project*. Bulletin 132-96.)

[xliv] The San Luis Reservoir is jointly owned by the Department and the U.S. Bureau of Reclamation, which operates the Central Valley Project.

[xlv] The SWP's share of gross storage in the reservoir is about 1,062,000 acre-feet.

[xlvi] Carrie Anderson, 1999, "Energy Use in the Supply, Use and Disposal of Water in California", Process Energy Group, Energy Efficiency Division, California Energy Commission, p.1.

[xlvii] California Department of Water Resources, 1996, *Management of the California State Water Project*. Bulletin 132-96.p.xix.

[xlviii] Metropolitan Water District of Southern California, 1999, "Fact Sheet" at: http://www.mwd.dst.ca.us/docs/fctsheet.htm. Summary of Metropolitan's Power Operation. February, 1999.

[xlix] According to MWD, "Metropolitan's annual dependable supply from the Colorado River is approximately 656,000 acre-feet -- about 550,000 acre-feet of entitlement and at least 106,000 acre-feet obtained through a conservation program Metropolitan funds in the Imperial Irrigation District in the southeast corner of the state. However, Metropolitan has been allowed to take up to 1.3 million acre-feet of river water a year by diverting either surplus water or the unused portions of other agencies' apportionments." Metropolitan Water District of Southern California, 1999, "Fact Sheet" at: http://www.mwd.dst.ca.us/docs/fctsheet.htm.

[l] Metropolitan Water District of Southern California, 1999, http://www.mwd.dst.ca.us/pr/powres/summ.htm.

[li] Metropolitan Water District of Southern California, 1999, Colorado River Aqueduct: http://aqueduct.mwd.dst.ca.us/areas/desert.htm, 08/01/99.

[lii] Among Metropolitan's power supply arrangements to be discussed is a provision for limited load shedding by Southern California Edison under which the Intake and Gene Pumping Plants can be shut down for certain limited periods of time during periods of peak electrical demands. Subsequent to such load shedding, Metropolitan occasionally operates all nine pumps at each of the Intake and Gene pumping plants (Total peak load of 311 MW) to refill the Copper Basin Reservoir.

[liii] Metropolitan Water District of Southern California, 1996, "Integrated Resource Plan for Metropolitan's Colorado River Aqueduct Power Operations", 1996, p.5.

[liv] Metropolitan Water District of Southern California, 1996, "Integrated Resource Plan for Metropolitan's Colorado River Aqueduct Power Operations", 1996, p.5.

[lv] Metropolitan Water District of Southern California, 1996, "Integrated Resource Plan for Metropolitan's Colorado River Aqueduct Power Operations", 1996, p.5.

[lvi] Metropolitan Water District of Southern California, 1999, "Summary of Metropolitan's Power Operation". February, 1999, p.1, http://aqueduct.mwd.dst.ca.us/areas/desert.htm.

[lvii] Metropolitan Water District of Southern California, 1999, http://www.mwd.dst.ca.us/pr/powres/summ.htm. MWD provides further important system information as follows: Metropolitan owns and operates 305 miles of 230 kV transmission lines from the Mead Substation in southern Nevada. The transmission system is used to deliver power from Hoover and Parker to the CRA pumps. Additionally, Mead is the primary interconnection point for Metropolitan's economy energy purchases. Metropolitan's transmission system is interconnected with several utilities at multiple interconnection points. Metropolitan's CRA lies within Edison's control area. Resources for the load are contractually integrated with Edison's system pursuant to a Service and Interchange Agreement (Agreement), which terminates in 2017. Hoover and Parker resources provide spinning reserves and ramping capability, as well as peaking capacity and energy to Edison, thereby displacing higher cost alternative resources. Edison, in turn, provides Metropolitan with exchange energy, replacement capacity, supplemental power, dynamic control and use of Edison's transmission system.